Rational Inattention, Menu Costs, and Multi-Product Firms: Micro Evidence and Aggregate Implications[*]

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Abstract

How do information and nominal rigidities affect multi-product firms? Using a firm-level survey from New Zealand, I show that firms that produce more goods have both 1) better information about aggregate inflation, and 2) more frequent but smaller price changes. To assess the aggregate implications of these firm-level findings, I develop a dynamic general equilibrium menu cost model with rationally inattentive multi-product firms. I parameterize the model to be consistent with the micro-evidence and show that the interaction of the menu cost and rational inattention frictions gives rise to a novel selection effect: firms that adjust prices have better information about underlying shocks than non-adjusters. This selection effect leads to an endogenous leptokurtic distribution of desired price changes that amplifies monetary non-neutrality. As a result, the real effects of monetary policy shocks in the one-good version of the model are nearly as large as those in the Calvo model. In the two-good version of the model, firms optimally choose to have better information about aggregate inflation than in the one-good version of the model, leading to a 20% reduction in the real effects of monetary shocks.

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1 Introduction

Macroeconomists have long been interested in the nature of firms' price-setting decisions and their expectations formation. While real business cycle models assume that firms with full information can set their prices freely at any given time, an extensive empirical literature that studies detailed micro data on firms' beliefs and pricing behavior finds ample evidence that neither of these assumptions holds in practice.[1] Instead, the data provide empirical support for models with either nominal or informational rigidities, or a combination of both, suggesting that nominal shocks, such as monetary policy shocks, can have real effects in an economy through these features.[2] Most of those models assume firms produce only one product;[3] as I show in this paper, however, only 20% of firms in New Zealand produce one product or product line.[4] A natural question is whether firms' price-setting and information acquisition decisions are independent of their product scope. If not, what are the macroeconomic implications of nominal and informational rigidities for monetary non-neutrality in a world of multi-product pricing? This paper takes a step toward answering these questions by 1) documenting the empirical characteristics of multi-product firms in terms of their price-setting and information acquisition decisions, and 2) developing a dynamic general equilibrium model with both nominal and informational rigidities for multi-product firms.

In this paper, I first investigate the empirical relationship between firms' product scope and their price-setting and information acquisition decisions using a representative survey of firms' macroeconomic beliefs in New Zealand. The survey illustrates pervasive inattention on the part of firms to macroeconomic variables, such as inflation and the growth rate of GDP. For example, backcast errors about the aggregate inflation rate, which are defined by the absolute value of firms' errors about inflation over the previous 12 months, are 4.5% on average across firms in the survey. My first empirical contribution is to document that this inattentiveness is systemat-

[1]For instance, the literature studying micro price data documents stickiness and lumpiness in price changes, and a large heterogeneity in price setting across firms. See Klenow and Malin (2010) and Nakamura and Steinsson (2013) for comprehensive reviews. Moreover, a recent growing literature on firms' expectations formation finds no evidence of full information. For example, Coibion et al. (2018a) and Kumar et al. (2015) show that firms in New Zealand are very inattentive to macroeconomic variables. Boneva et al. (2019) also finds wide dispersion of expectations across firms in the U.K.

[2]New Keynesian models depart from the flexible price assumption by introducing various types of stickiness in price setting such as menu costs or Calvo frictions. Informational friction models, such as Mankiw and Reis (2002), Sims (2003), and Woodford (2003), assume that firms do not have full information about underlying shocks while their expectations are rational. I extensively discuss models with both nominal and informational rigidities in Literature Review.

[3]Notable exceptions are Midrigan (2011) and Alvarez and Lippi (2014), who study menu cost models with multi-product firms, and Pasten and Schoenle (2016), who build a rational inattention model with multi-product firms.

[4]Bhattarai and Schoenle (2014) finds that more than 98% of prices included in the US producer price index are set by firms with more than one product.

ically related to firms' product scope: firms that produce a greater number of goods are better informed about aggregate inflation. I find that the backcast errors about aggregate inflation are decreasing in firms' number of products conditional on firm-level characteristics such as the size and age of firms. Moreover, firms that produce a greater number of goods are also willing to pay more for the information about future inflation. This implies that firms with more products have incentives to process more information about the aggregate economic conditions. To the best of my knowledge, these results are the first empirical evidence documenting differential information acquisition decisions of firms based on the number of products they sell.

My second empirical finding is that firms change their prices infrequently, and the frequency and size of price changes are also systematically related to their product scope. I show that firms with a greater number of products change their prices more frequently, and conditional on price changes, they change by smaller amounts. This implies that there are economies of scope motives in firms' price-setting decisions, which is consistent with the previous empirical literature using different micro price data.[5] Jointly, these results illustrate that the scope of products sold by firms affects both their information acquisition decisions and their price-setting decisions.

Can existing models with multi-product firms explain these empirical findings? On the one hand, a rational inattention model with multi-product firms is consistent with only the first finding of the relationship between firms' product scope and their inattentiveness to aggregate economy. Pasten and Schoenle (2016), for example, show that multi-product firms have more incentive to process information about aggregate conditions because the information can be incorporated into pricing decisions for all of their products. This is called economies of scope in information processing. However, this model cannot explain the second finding since firms in the model are continuously changing their prices based on imperfect information: there is no price stickiness at the micro level. On the other hand, models with menu costs for multi-product firms can only explain the second finding. Midrigan (2011) and Alvarez and Lippi (2014), for example, consider models with a single fixed menu cost for multi-product firms. In these models, if a firm decides to pay the fixed cost to change one of its prices, it can change all of its prices even if those prices are not far away from their optimal prices. As a result, for a fixed menu cost, the firm changes its prices more frequently and by smaller amounts when it prices a greater number of products. However, since these models are based on the assumption of full information rational expectation for firms, they cannot explain the pervasive informational rigidities observed in the data.

[5] Using the U.S. PPI micro data, Bhattarai and Schoenle (2014) find that multi-product firms change their prices more frequently and by smaller amounts. Parker (2017) also finds the similar findings using New Zealand data. Stella (2018) estimate common menu costs for multi-product firms and find there substantial economies of scope in price setting.

Moreover, the aggregate implications of firms' product scope for monetary non-neutrality in menu cost models are very different from those in rational inattention models. In particular, Midrigan (2011) and Alvarez and Lippi (2014) show that in menu cost models with multi-product firms, the real effects of monetary policy shocks are *increasing* in the number of products firms produce. Monetary non-neutrality increases since the economies of scope from the menu cost technology weaken selection effects of price changes, which act as a strong force to reduce the real effects of monetary shocks in a standard single-product menu cost model studied in Golosov and Lucas (2007). On the other hand, Pasten and Schoenle (2016) show that in the rational inattention model with multi-product firms, monetary non-neutrality is *decreasing* in firms' product scope. Since multi-product firms want to be more informed about aggregate shocks due to the economies of scope in information processing, they respond more strongly to monetary policy shocks by learning about them more rapidly and therefore changing their prices more rapidly. This strong and fast response of prices implies a small response of aggregate output following the shocks. Thus, the real effects of monetary policy shocks decrease in the number of products firms produce. In sum, neither model with multi-product firms can account for the empirical relationship between firms' product scope and their decisions on both price-setting and information acquisition, and they have contradictory implications of firms' product scope for monetary non-neutrality. This calls for a new model, which is disciplined by the empirical facts, to study the macroeconomic implications for monetary non-neutrality.

To this end, I develop a model of multi-product firms facing both nominal and information rigidities. In the model, firms are rationally inattentive and choose their optimal information set subject to costs to acquiring and processing information. Given their optimal information choices, firms decide whether to change all of their prices by paying a single fixed menu cost which is independent of the number of products that change prices. Each firm faces two types of shocks: idiosyncratic good-specific shocks and an aggregate monetary shock. I show that this model displays a number of novel properties in terms of firms' optimal information choices and their price-setting decisions. First, firms make mistakes in their pricing decisions since their choice of timing and size of price changes is based on imperfect knowledge about their true marginal costs. Second, while firms' optimal pricing rule follows an S-s rule as in a standard menu cost model, under rational inattention the inaction bands are time-varying, and depend on firms' subjective uncertainty about underlying shocks: firms that are more uncertain about the underlying shocks have wider inaction bands. Third, the interaction between menu costs and rational inattention introduces a new selection mechanism in information processing: price adjusters choose to collect more information about the underlying shocks than non-adjusters. Lastly, there are the economies of scope motives in information processing: firms' subjective uncertainty about aggregate shocks decreases in their number of products.

I embed this setup of firm decision-making into a fully-fledged dynamic general equilibrium model to study the macroeconomic implications of product scope and its interaction with both nominal and information rigidities for monetary non-neutrality. I then compare the macroeconomic dynamics in one-product vs two-product versions of firm decision-making.[6] I calibrate three key parameters, the size of menu costs, the size of informational costs, and the size of idiosyncratic good-specific shocks to match key moments observed in the survey data. Specifically, I use three target moments from the survey data to discipline model parameters: the frequency and size of price changes, and the slope of a backcast errors curve on the number of products. The first two help to calibrate the menu cost parameter, while the third helps to calibrate the informational cost parameter.

One key contribution of this paper is to characterize how the interaction between rational inattention and menu costs affects firms' decisions and to document the implications of this interaction for amplification of monetary policy shocks in a dynamic general equilibrium model. I find that this interaction *endogenizes* a leptokurtic distribution of desired price changes through the new selection mechanism in information processing about idiosyncratic shocks. Consider an economy with a large number of single-product firms.[7] At the beginning of each period before firms get their idiosyncratic shocks, their prior beliefs about price gaps are all within their inaction bands, implying a high kurtosis in the distribution of *prior* price gaps. After being hit by Gaussian idiosyncratic shocks, the distribution of true price gaps in the economy is Gaussian. Firms then all choose their optimal Gaussian signals and update their estimates of price gaps, but they do not do so in the same way. Firms which think that their price gap is well-within their inaction bands and who think it is unlikely that they will need to change prices have little incentive to collect much new information: they choose to remain quite uninformed. In contrast, firms that think they are close to the boundaries of their inaction regions have a high incentive to collect information and therefore choose to become more informed. This results in a leptokurtic distribution of *posterior* price gaps or equivalently their desired price changes. Since actual price changes are based on firms' posterior estimates of their price gaps, the leptokurtic distribution implies that there is small fraction of prices around the inaction bands. In turn, compared to the standard pure menu

[6] I discuss the implications of introducing higher numbers of products in section 5.1.

[7] While the mechanism I explain here also operates in the two-product model, the single-product model gives a clear comparison to a standard (pure) menu cost model with single-product firms, such as Golosov and Lucas (2007).

cost model with Gaussian shocks, the endogenous leptokurtic distribution in my model weakens selection effects of price changes. In the quantitative exercise informed by the micro-level survey data, I show that this endogenous leptokurtic distribution amplifies the impact effects of the monetary policy shock by 30% compared to the single-product menu cost model with fully informed firms. Together with a large degree of inattention to the monetary policy shocks, this effect leads my baseline single-product model to generate real effects of monetary shocks that are nearly as large as those in the Calvo sticky price model.

A second novel contribution of the model is to characterize the economies of scope motives in both price setting and information processing and to document the implications of the multi-product pricing for the real effects of monetary shocks. The economies of scope from selling multiple products affects both information and pricing decisions of firms. Since paying the menu cost allows firms to change the prices of all of their goods simultaneously, price changes are perfectly synchronized within firms, and there are lots of small price changes as well as large price changes. This weakens selection effects of price changes as emphasized in Midrigan (2011) and Alvarez and Lippi (2014), and should tend to amplify the real effects of monetary policy shocks in the two-product model. On the other hand, I also find a significant scope motive in information processing: the value of information about aggregate shocks increases in firms' product scope. Under my benchmark calibration, The weight that firms place on the signal about the monetary shocks increases twofold in the two-product model compared to the single-product model. Consistent with my empirical evidence, this implies that multi-product firms have better information about aggregate conditions compared to the single-product firms. Since multi-product firms learn rapidly about the monetary policy shocks, this force will tend to reduce the real effects of nominal shocks. The quantitative analysis shows that cumulative output effects decrease by 20% in the two-product model compared to the single-product model. The half-life of the output response also decreases from 7 months in the single-product model to 6 months in the two-product model. This implies that the scope motive in information processing quantitatively dominates its effect on pricing decisions, thereby leading to reduced effects of nominal shocks on economic activity as we move to a multi-product environment.

Literature Review. This paper builds on and contributes several strands of literature. First, it relates to a recent literature studying how firms form their expectations and how their expectation affects their decisions. Using the same survey of New Zealand firms' macroeconomic belief that I use in this paper, Kumar et al. (2015) and Coibion et al. (2018a) study determinants of firms' inattentiveness to aggregate economic conditions, how firms update their beliefs in a response to new information, and how changes in their belief affect their decisions. Frache and Lluberas (2019) study how firms form their inflation expectations and how this is affected by the acquisition of new information using survey data from Uruguay. Grasso and Ropele (2018) study how firms' investment decisions are affected by their inflation expectations using Italian business survey data and Coibion et al. (2019) find causal effects of inflation expectations on firms' decisions on price changes and employment as well as credit demand using the same data. Afrouzi (2019b) shows that firms facing more competitors are better informed about aggregate inflation. The new empirical contribution in this paper relative to the existing literature is to show that firms producing a greater number of products are better informed about current aggregate inflation. Moreover, I provide experimental evidence that firms with a greater number of products do not respond strongly to exogenously given new information about aggregate inflation, which is consistent with the finding that they are better informed about it.

I also contribute to the literature studying the real effects of monetary policy shocks using menu cost models and rational inattention models. Golosov and Lucas (2007) show that a standard menu cost model calibrated to the frequency and size of price changes in the U.S. micro data cannot generate sizable monetary non-neutrality because of strong selection effects of price changes.[8] Midrigan (2011) introduces two-product firms in the model and leptokurtic productivity shocks to calibrate more micro moments observed in the U.S. retail data. He shows that selection effects of price changes are weaker due to the economies of scope in price changes and the leptokurtic shocks. Using a continuous-time multi-product menu cost model, Alvarez and Lippi (2014) show how the frequency and size of price changes are related to the number of products firm produce and find that the cumulative output effects of monetary shocks increase in the number of products firms produce. Following the seminal work by Sims (2003), the rational inattention literature provides another mechanism through which monetary policy shocks can have real effects.[9] Maćkowiak and Wiederholt (2009) study a standard Linear Gaussian Quadratic rational inattention problem where firms have both idiosyncratic and aggregate shocks. They find that since idiosyncratic shocks are more volatile, firms pay less attention to aggregate shocks, which generates large monetary non-neutrality. Pasten and Schoenle (2016) show that when firms produce multiple products, this raises their incentive to process information about aggregate shocks

[8] Gagnon et al. (2013) study the effect of large inflationary shocks on the timing of price changes using Mexican CPI data and find direct support for a selection effect. Carvalho and Kryvtsov (2018) finds evidence of strong price selection across goods and services using detailed micro-level consumer price data for the UK, the US, and Canada.

[9] See, for instance, Sims (2010) and Maćkowiak et al. (2018) for comprehensive reviews.

since the information about aggregate shocks can be incorporated into all their pricing decisions. As a result, monetary non-neutrality decreases in the number of products firms produce. My theoretical contribution is to combine all three elements, menu cost, rational inattention, and multi-product firms, in a unified framework to study the real effects of monetary policy shocks.

The theoretical model I study in Section 3 is different from previous models with both nominal rigidities and informational frictions. For example, Gorodnichenko (2008) studies a menu cost model with a partial information acquisition with a fixed observational cost. Alvarez et al. (2011) and Alvarez et al. (2017) study models with both menu costs and observational costs, where firms decide when they observe idiosyncratic shocks by paying a fixed cost. In these models, firms can perfectly observe the state of the economy by paying the fixed cost. Bonomo et al. (2019b) also develop a model with both menu costs and observational costs, where either idiosyncratic shocks or aggregate shocks are free to observe, and show that free idiosyncratic information is necessary for the model to match micro moments and generate large monetary non-neutrality. Woodford (2009) and Stevens (2019) develop models with consideration costs, where firms' price reviews incur a fixed cost and the review decision is made on the basis of incomplete information. However, in these models, firms have perfect information once they pay the consideration costs. Dupor et al. (2010) combine exogenously random times of observation as in Mankiw and Reis (2002) with Calvo sticky prices while Knotek (2010) and Klenow and Willis (2007) propose models in which firms change prices by paying a menu cost and infrequently update their information on aggregate conditions while they perfectly observe their idiosyncratic condition. In contrast to these papers, I combine a rational inattention model and a menu cost model in which firms choose directly their optimal signals about true optimal prices in each period given an information constraint. Afrouzi (2019a) also develops a continuous-time model with both rational inattention and nominal rigidities, where the nature of nominal rigidities nests both menu costs and the Calvo sticky price model. This paper finds that there is selection in information acquisition, in which price non-adjusters do not acquire any information about the underlying shocks in the model with the Calvo extreme. My model is different from this since firms in my model set prices for multiple products. Moreover, the combination of menu costs and rational inattention gives rise to a novel selection effect in information processing which leads to an endogenous leptkurtic distribution of desired price changes. This is a unique microfoundation of a fat-tail distribution of firms' desired price changes while previous literature on menu costs rely on some distributional assumption about the underlying shocks to generate it (e.g. Gertler and Leahy (2008); Midrigan (2011); Vavra (2013); Karadi and Reiff (2019); Baley and Blanco (2019)). Figure A.1 in appendix shows how this paper fits within the literature on menu costs and rational inattention models.

The paper is organized as follows. Section 2 evaluates the empirical relationship between the number of products firms produce with 1) their attentiveness to aggregate inflation, and 2) the frequency and size of price changes. Given that previous monetary models with multi-product firms cannot explain the two stylized facts I present in Section 2, I develop a menu cost model with rationally inattentive multi-product firms in Section 3 and study firms' optimal information acquisition and pricing decisions. In Section 4, I extend the baseline model to a fully calibrated dynamic general equilibrium model and simulate the model economy with a large number of firms to study the distributional characteristics of firms' price changes and their information acquisition. I also study the real effects of monetary policy shocks in the model and discuss the underlying mechanisms with counterfactual analysis. In Section 5, I study an extension of the baseline model to show the robustness of the baseline results. Section 6 concludes.

2 Empirical Evidence

In this section I present two novel stylized facts about how firms' product scope relates 1) to their attentiveness to aggregate economic conditions and 2) to the frequency and size of their price changes. To this end, I use a quantitative survey of firms' expectations about macroeconomic conditions in New Zealand. Coibion et al. (2018a) and Kumar et al. (2015) provide a comprehensive description of the survey. The survey was conducted in multiple waves among a random sample of firms in New Zealand with broad sectoral coverage. There are two novel empirical contributions in this paper relative to the previous studies that have used the data.[10] First, I show that firms producing a greater number of products are better informed about the current aggregate inflation. Second, I document that the duration of price changes and the average size of price changes decrease in the number of products firms produce.

Based on these two stylized facts, I discuss how these findings are related to predictions of modern monetary models such as models with nominal rigidities (e.g. Calvo, Taylor, menu costs models) and models with informational rigidities (e.g. rational inattention, sticky/noisy information, observational costs models). I argue that these models cannot explain both stylized facts simultaneously. Moreover, I show that each model has different aggregate implications of multi-

[10]Several papers use the data to characterize how firms form their expectation. For example, Afrouzi (2019b) shows that strategic complementarity decreases with competition, and documents that firms with more competitors have more certain posteriors about the aggregate inflation. Also, Coibion et al. (2018b) evaluate the relation between first-order and higher-order expectations of firms, including how they adjust their beliefs in response to a variety of information treatments.

product pricing for monetary non-neutrality. For example, in rational inattention models, monetary non-neutrality decreases in the number of products that firms sell while it increases in the number of products in menu cost models. These empirical and theoretical challenges of previous monetary models with multi-product firms call for a new model which is disciplined by the micro evidence to study the aggregate implications. To this end, I develop a new dynamic menu cost model with rationally inattentive multi-product firms, which I will discuss in the next section.

2.1 Number of Products and Knowledge of Aggregate Inflation

In this subsection, I first evaluate the relationship between firms' number of products and their attentiveness to current aggregate economic conditions. To identify the number of products firms produce, I use the second wave of the survey, implemented between February and April 2014. In the survey, firms' managers are asked the following question:

> **"In addition to your main product or product line, how many other products do you sell?"**
>
> *Answer*: .... products

Table A.1 in appendix shows the summary statistics of firms' number of products by industry. The median of firms' number of products is 9 while it is 7 when firms in retail and wholesale trade sectors are excluded. In the baseline regressions, I exclude those retail and wholesale trade firms since their strategy for pricing and information processing is likely to be different from that of firms in other sectors, such as manufacturing and service industries.[11] In the data, a relatively large number of firms (about 18% of all firms) sell only one product or have one product line compared to other studies.[12] There are two reasons of the large fraction of single-product firms in the survey. First, firms in the survey are relatively small. Average employment of firms are about 31 and the largest firms have 600 employees. Second, the question is about the number of products or product lines of a firm. Since there might be several similar types of products in a product line, this question captures firms' perception of the unit of their product scope. In fact, I find that the average of firms' output share of their main product (or product line) is about 60% excluding single-product firms implying that firms define their unit of product scope a bit broadly.

Firms' attentiveness to aggregate economic conditions, referred to as backcast error about aggregate inflation, is defined to capture firms' knowledge about current aggregate economy. Given

[11] Including retail and wholesale trade firms in the sample does not change the baseline results that I show below. For example, see A.3 in appendix.

[12] For example, Bhattarai and Schoenle (2014) document that 98% of all prices are set by firms with more than one good in the micro data that underlie the calculation of the U.S. PPI.

that recent aggregate economic conditions are largely observable in real-time, I define the backcast error as the absolute values of difference between actual past 12 month aggregate inflation and managers' beliefs about it from the survey.[13] As documented in Coibion et al. (2018a), firms are not well-informed about the current aggregate inflation by making 4.5% backcast errors on average.[14] On top of that, I find that firms' errors are related to their number of products.[15] Figure 1 shows that there is a clear positive relationship between the number of products firms produce and their attentiveness to aggregate inflation. The left panel shows that firms with smaller product scope have large backcast errors on average. In the right panel, I show the relation between firms' product scope and their willingness to pay for professional forecasts about future inflation from the fourth wave of the survey. The latter is another measure of firms' incentive to be attentive to aggregate economy. Here, I find a positive correlation between the number of products firms produce and their willingness to pay for professional forecasts about future aggregate inflation. This implies that firms with larger product scope are likely to pay more attention to the aggregate condition.

One potential concern is that this negative correlation between the number of products firms produce and their knowledge of the current aggregate inflation is driven by other firms characteristics. For example, as big firms are likely to have a large product scope and they might have a large capacity to process information, one might think that the negative correlation stems from the size of firms rather than their product scope.[16] To address this, I regress firms' inattention to inflation, as measured 1) by their absolute errors about recent inflation rates and 2) by their willingness to pay for professional future inflation forecasts, on log of firms' number of products, conditional on firm-level characteristics, such as log of firms' age, log of total employment, foreign trade share, firms' number of competitors, their beliefs about price difference from their competitors, and the slope of the profit function.[17] Column (1) of Table 1 shows that firms with a greater number of products are likely to have small backcast errors about current aggregate inflation and

[13] Consumer Price Index (CPI) is used to calculate the actual past 12 month aggregate inflation. The baseline results are quantitatively similar when I use GDP deflator or Produce Price Index to calculate the actual inflation rate.

[14] One might have a concern that whether firms do not know what the inflation means. However, Kumar et al. (2015) document that 86% of firm managers in the survey could correctly explain what inflation means and they believed that statistical agencies were credible in measuring price changes. Coibion et al. (2018a) also highlight that the large errors are not driven by specific language about the definition of inflation used in the survey.

[15] See Table A.2 in appendix for the summary statistics of the firms' backcast error about aggregate inflation by the quartiles of firms' product scope within different industries.

[16] Kaihatsu and Shiraki (2016) show that size of firms significantly affects differences in their inflation expectations. Also, Frache and Lluberas (2019) find that large firms have lower forecast errors about aggregate inflation than small firms.

[17] The slope of a firm's profit function is calculated as the ratio of by how much a firm could increase its profit (as a percent of revenue) if it could reset its price freely at the time of the survey relative to the percent price change the firm would implement if it could reset its price freely at the time of the survey.

also willing to pay more on professional forecasts about future aggregate inflation. Column (2) shows the significant negative correlation after controlling for industry fixed effects.

Another potential concern is that the survey respondents, here managers of firms, have different ability or incentive to pay attention to aggregate economic conditions.[18] To address this issue, in Column (3), I report the regression results after controlling for managers' characteristics, such as the age of the each firm's manger, and education, income-level, and the manager's tenure at the firm. Again, after controlling the managers characteristics, I find the negative correlation between firms' number of products and their knowledge of or attentiveness to aggregate inflation.

2.1.1 Information Updates

Firms revise their expectations when they receive new information. Suppose firm i has prior belief about aggregate inflation which is normally distributed with mean μ_i and precision τ_i. Then each firm receives a common signal s which is also normally distributed with precision ψ_s. Firms update their belief in Bayesian manner and get posterior p_i:

$$p_i = \mu_i + \frac{\psi_s}{\psi_s + \tau_i}(s - \mu_i) \tag{1}$$

Firms update their belief by more when the signal has a greater precision or their prior precision is smaller. This implies that if firms with a greater number of products have better information about aggregate inflation, they revise their belief by less given precision of the signal. I can test this implication more formally using the following regression:

$$p_i = c + \beta\mu_i + \gamma N_i^{\text{product}} \times \mu_i + \delta N_i^{\text{product}} + \varepsilon_i$$

where N_i^{product} is a measure of firm i's number of products and the constant term absorbs the common signal. I would expect $\gamma > 0$ if firms with a greater number of products revise their expectations by less.

In the fourth wave of the survey, firms were asked to assign probabilities for future inflation, from which I can compute their mean forecast. This mean forecast is firms' prior (μ_i) about future inflation. Randomly assigned firms were given additional information about aggregate inflation, which is the common signal (s).[19] After receiving this information, firms were asked for a point

[18] For example, Tanaka et al. (2019) show that managers' GDP forecasting ability is linked to their management ability and experience.

[19] There were five group of firms which receive information about inflation: 1) the most recent realization of inflation, 2) the target inflation of the central bank, 3) the most recent professional forecaster of inflation, 4) both the central

forecast for future inflation, which is their posterior belief (p_i) about it.

Table 2 shows the regressions results with different specifications.[20] Column (1) shows that firms revise their belief toward the signal, which is consistent with Bayesian updating.[21] Column (2) shows the regression result when I use a dummy variable, which is one if a firm sells more than or equal to four products, for the interaction term. The positive coefficient on the interaction term implies that firms with less than four products revise their expectations about inflation by more when they receive new information. Column (3) shows that this is also true when I use a continuous variable (log of firms' number of products). Including firms' size and the interaction between the size and prior does not change the results (column (4)). Finally, I use a proxy for firms' number of products: share of total product value for main product. This share should be one If firms sell only one good, and will be small when firms sell many products. I use one minus this share as a proxy for firms' number of products. Column (5) shows that the interaction coefficient is significantly positive, implying that multi-product firms might update their information by less when they receive new information.

In sum, the sensitivity of firms' inflation beliefs to new information decreases in the number of products, which is consistent the previous finding that firms with a greater number of products have better information about aggregate inflation.

2.1.2 Treatment Effects of Providing Information

Since firms' revision of expectations differs by their product scope given new information, one might expect that firms also change their actions differently. I take one more step to test this implication. In the fifth wave of the survey, firms are asked about their plans for changes in future investment, employment, price, and wage, over the next six months. Then, randomly selected subset of firms were told about the Reserve Bank of New Zealand (RBNZ)'s inflation target. After six months, the follow-up wave asked firms about the outcomes for each of these variables over the previous six months. The gap between these actual outcomes and their previous forecasts captures the extent to which their actions deviated from their ex-ante forecast, which help us to assess the treatment effects of providing new information on their actions. If firms with a greater number of products have better information about aggregate inflation, they would not revise their

bank target and the professional forecast, and 5) the average inflation forecast of other firms in the survey. One piece of additional information is given to firms in each group. See section 5.1 in Coibion et al. (2018a) for details of the experiment.

[20] All regressions include fixed effects for each treatment group.

[21] This is clearly seen when the equation (1) is rewritten as $p_i - \mu_i = \frac{\psi_s}{\psi_s+\tau_i}(s - \mu_i)$. Then, the estimated coefficient captures $\beta = 1 - \frac{\psi_s}{\psi_s+\tau_i}$.

expectations further, and do not change their actions relative to the control group which did not receive information about the central bank's inflation target.

Table 3 shows the treatment effects of information about RBNZ's inflation target. First, firms with a smaller number of products which are treated by the information immediately decrease their inflation expectations relative to firms with the same number of products in the control group. This is consistent with the previous finding of information updating. After sixth months later, those firms with a smaller number of products in the treatment group have prices and investment below their ex-ante expectation than firms in the control group. In contrast, I find no significant deviation of actions for information treated firms with a greater number of products compared to firms in the control group. This is another evidence that firms with a greater number of products have better information about aggregate inflation, and thus they do not strongly revise their expectations and change their actions when they are given new information about it.

2.2 Number of Products and Size and Frequency of Price Changes

In this subsection, I document the relationship between the number of products firms produce and the frequency and size of price changes. The survey asks to firms' managers the following question:

> **"Please report when and by how much you expect to next change the price of your main product and your second main product.** Please provide a numerical answer in months for the durations (e.g. "0" for within the next month, 1 for one month from now, ...) and a percentage answer for the size of the price change (e.g. "+10%" for a 10% increase in price or "-10%" for a 10% decrease)

After controlling firms' characteristics and their incentive to change their prices, this question quantifies the frequency and the size of firms' price changes.

Table 4 shows the relationship between firms' number of products and their frequency and size of price changes. Panel A shows that after controlling for firm-level characteristics, the duration of price changes is negatively correlated with the number of products firms produce. This means that firms with a greater product scope are more likely to change their prices frequently. This negative correlation is even stronger when I control for managers' characteristics. In Panel B, I also find that after controlling for the industry fixed effects, there is a negative correlation between the number of products firms produce and the size of price changes. This shows that conditional on price changes, firms with a greater product scope change their prices by smaller amounts.

Previous studies also find the negative correlations between the number of products firms produce and the duration and the size of price changes. For example, using micro data that underlie the calculation of the U.S. PPI, Bhattarai and Schoenle (2014) show that firms with larger product scope are more likely to change their prices frequently, and conditional on price changes, they change by smaller amounts. Parker (2017) also finds that this negative correlation between firms' product scope and the duration and the size of price changes using another New Zealand firms' survey data from Statistics New Zealand in 2010.

2.3 Summary and Relation to Monetary Models

Can existing monetary models with multi-product firms explain both the negative correlation of firms' product scope and their knowledge of aggregate economy and the negative correlation of firms' product scope and the duration and size of price changes? In rational inattention models with multi-product firms such as Pasten and Schoenle (2016), the inattentiveness to aggregate shocks is *decreasing* in the number of products firms produce. In a presence of both goods-specific shocks and aggregate shocks, multi-product firms want to be informed more about the aggregate shocks than the goods-specific shocks since the aggregate shocks will affect marginal costs of all of their products. Since the value of information about the aggregate shocks increases in the number of products firms produce, this model implies the negative correlation between the number of products firms produce and firms' inattentiveness to aggregate shocks. However, this model cannot explain infrequent price changes of firms since firms always respond to shocks by adjusting their prices.[22] Thus, this model implies no correlation between the number of products firms produce and firms attentiveness to the aggregate shocks.

On the other hand, in menu cost models with multi-product firms such as Midrigan (2011) and Alvarez and Lippi (2014), firms with a greater number of products are likely to change their prices frequently and by smaller amounts. This is consistent to my second empirical finding of the negative correlation between firms' number of products and the duration and the size of price changes. However, firms in this model are fully informed about aggregate shocks. This full-information assumption sharply contrasts to the fact that firms in the survey data have large errors about their perception about current inflation rate of the economy.

Moreover, aggregate implication of the firms product scope for monetary non-neutrality in the

[22] Here I consider Linear-Quadratic-Gaussian (LQG) rational inattention models that are developed to study aggregate effects of monetary policy shocks, such as Maćkowiak and Wiederholt (2009, 2015) and Afrouzi (2019b). Recent studies, such as Sims (2006), Matějka (2015), and Jung et al. (2019), develop rational inattention models beyond LQG settings that deliver discreteness in agents' choices. However, these models have not been developed to study aggregate economy in a general equilibrium setup.

rational inattention model is very different that in the menu cost model. Since firms with a greater product scope have more incentive to process information about monetary shocks in the rational inattention model with multi-product firms, the real effects of monetary shocks are *decreasing* in the number of products firms produce. However, in the menu cost model with multi-product firms, monetary non-neutrality *increases* in the firms' number of products since selection effects of price changes from menu cost technology are weak due to many small and large price changes as shown in Alvarez and Lippi (2014).[23]

In sum, neither model with multi-product firms can account for the empirical relationship between firms' product scope and their decisions on both price-setting and information acquisition, and they have contradictory implications of firms' product scope for monetary non-neutrality. This calls for a new model, which is disciplined by the empirical facts, to study the macroeconomic implications for monetary non-neutrality. This is the goal of the following sections.

3 Price Setting with Menu Costs for a Rationally Inattentive Multi-Product Firm

In this section I develop a menu cost model for a rationally inattentive multi-product firm. Before constructing a fully-fledged dynamic general equilibrium model in the next section, I consider a decision problem of a rationally inattentive firm that faces both product-specific shocks and an aggregate shock. The firm chooses a set of optimal signals about the underlying shocks, and pays a single fixed cost (i.e. a menu cost) to change all its prices. I characterize the firm's optimal information choices and price setting behavior. The goal of this section is to show that (1) how the endogenous information choices are affected by the presence of menu costs and (2) how the firm's product scope affects its information acquisition and price setting decisions.

First, to show the interaction between menu costs and rational inattention frictions, I compare a single-product firm's optimal decision rules with and without informational costs. When information is costly, the rationally inattentive firm should decide how much acquire new information about its marginal costs. Moreover, given menu costs, this firm decides whether it changes its price or not based on its information set. Optimal pricing rule implies that the more this firm is

[23]Table A.4 in appendix shows that other models with nominal or information rigidities cannot explain those two stylized facts I find in this section. For example, Calvo or Taylor sticky price models imply that the frequency and size of price changes are independent of the number of products since the frequency of price changes are exogenously given in the model. Similarly, sticky and noisy information models imply that the attentiveness to aggregate conditions is independent of firms' number of products since information acquisition is exogenous in those models. Observational cost models such as Alvarez et al. (2015) also imply the independence results since it is assumed that firms use steady-state policy rules which are not affected by aggregate shocks in the model.

uncertain about the underlying shocks, the less it is likely to change its price. This implies that the timing of price changes is selected as the firm is likely to change its price when it has more information about the shocks. This interaction of nominal and informational rigidities plays a key role in amplifying monetary non-neutrality in the dynamic general equilibrium model that I will discuss in the next section.

Second, given both menu costs and rational inattention frictions, I investigate how a two-product firm is different from a single-product firm in terms of its information and price setting decisions to highlight economies of scope motives in both price changes and information processing. I show that the two-product firm optimally chooses to be more informed about the aggregate shock than the single-product firm since information about the aggregate shock can be utilized for its pricing decisions for all goods. Moreover, due to the single fixed menu cost of price changes, the two-product firm changes all its prices at the same time. This scope motive in price changes generates small price changes which are absent in the single-product firm economy. These two motives of economies of scope are also key elements for monetary non-neutrality in the general equilibrium model with multi-product firms.

3.1 A Rationally Inattentive Firm's Problem

Consider a multi-product firm that produces N goods, indexed by $j = 1, 2, \cdots, N$. The firm sets its price of good j, $p_{j,t}$, to match a (frictionless) optimal price, $p^*_{j,t}$.[24] Suppose its optimal price of good j consists of two components, a good-specific shock, $a_{j,t}$, and an aggregate shock, m_t:

$$p^*_{j,t} = a_{j,t} + m_t.$$

I assume that both shocks follow random walk processes:[25]

$$\begin{aligned} a_{j,t} = &\quad a_{j,t-1} + \varepsilon^a_{j,t}, \quad \varepsilon^a_{j,t} \sim N(0, \sigma_a^2) \;\text{ for }\; j = 1, 2, \cdots, N \\ m_t = &\quad m_{t-1} + \varepsilon^m_t, \quad \varepsilon^m_t \sim N(0, \sigma_m^2) \end{aligned}$$

[24]Small letters denote log deviation from (firctionless) steady state. When we consider the firm as a monopolistically competitive producer, without any frictions its optimal reset price of good j is a constant markup over the marginal cost: $P^*_{j,t} = \mu \times MC_{j,t}$. Then the log deviation of optimal price is that of marginal cost: $p^*_{j,t} = mc_{j,t}$.

[25]The random walk process of the underlying shock is a common assumption in the menu costs literature since it simplifies the firm's problem by making it chooses its price gaps, which are defined by the difference between the frictionless and the actual prices. See Barro (1972), Tsiddon (1993), and Alvarez and Lippi (2014) among others.

where $\varepsilon^a_{j,t}$ and ε^m_t are independent and identically distributed. A flow loss of the firm in profits is the sum of the distance between its price of each good and the (frictionless) optimal price:[26]

$$B\sum_{j=1}^{N}\left(p_{j,t}-p^*_{j,t}\right)^2$$

where B captures the concavity of the firm's profit function with respect to each prices.

This firm is rationally inattentive. At the beginning of each period, the firm has to choose how precisely it wants to observe its current set of (frictionless) optimal prices subject to a cost of information processing . Formally, at time t, the firm chooses a set of signals about both good-specific and aggregate shocks from a set of available signals, $\mathcal{S}_t = \{\mathcal{S}^a_{j,t}\}_{j=1}^N \cup \mathcal{S}^m_t$, such that

$$\begin{aligned}
\mathcal{S}^a_{j,t} &= \{a_{j,t}+\eta_{j,t}\xi^a_{j,t} : \eta_{j,t}\geq 0,\ \xi^a_{j,t}\sim N(0,1)\},\ \text{ for } j=1,2,\cdots,N\\
\mathcal{S}^m_t &= \{m_t+\eta_{m,t}\xi^m_t : \eta_{m,t}\geq 0,\ \xi^m_t\sim N(0,1)\}.
\end{aligned}$$

where $\{\xi^a_{j,t}\}_{j=1}^N$ and ξ^m_t are the firm's rational inattention errors.[27] Let S^{t-1} be the firm's information set at the beginning of period t before it receives new signals about its frictionless optimal prices. At each time t, given S^{t-1}, the firm chooses a set of the signals $s^a_{j,t}\in\mathcal{S}^a_{j,t}$ for $j=1,2,\cdots,N$, and $s^m_t\in\mathcal{S}^m_t$ subject to the cost of information processing. Then, the firm's information set evolves as follows:

$$S^t = S^{t-1}\cup s_t$$

where $s_t = \{\{s^a_{j,t}\}_{j=1}^N, s^m_t\}$. This implies that the firm does not forget information over time. This "no-forgetting constraint" implies that the current information choice has a continuation value and thus the optimal information choice is a solution of a dynamic information acquisition problem.

I assume that the cost of information is linear in Shannon's mutual information function. The firm pays ψ units of its (per-good) revenue for every bit of expected reduction in uncertainty, where uncertainty is measured by entropy. Denote this cost as $\psi\mathcal{I}(s_t;\{p^*_{j,t}\}_{j=1}^N|S^{t-1})$, which will be defined later in this section.

At each period, based on its optimal choice of information, the firm chooses whether to change its prices. I assume that the firm can change all its prices by paying a single fixed cost, θ. This cost

[26] While I take this as an assumption, this loss function can also be derived as a second order approximation to a twice differentiable profit function around the non-stochastic steady state.

[27] This set of available signals is based on three assumptions about the firm's information structure. First, the firm chooses $N+1$ independent signals for each shock, implying that paying attention to aggregate conditions and paying attention to good-specific idiosyncratic conditions are separate activities. Second, each signal is Gaussian. Third, all noise in signals is idiosyncratic and independent.

is independent of the number of prices the firm changes.

Figure 2 shows the timing of events for the firm's problem: at the beginning of period t, the firm starts with a priori information set, S^{t-1}, and forms a prior over its optimal prices at that time. Then it chooses a new set of signals, s_t, subject to the cost of information processing and updates its information set, S^t. Given this time t information set, the firm decides whether to change its prices and pays the fixed cost θ or to wait until the next period without changing its prices. If the firm decides to change its prices, it also chooses how much it changes the prices. Thus, the firm optimally chooses a set of signals about the underlying shocks and prices ($p_{j,t}$) over time, contingent on the evolution of their beliefs. Formally, the firm's problem is as follows:[28]

$$\begin{aligned}\min_{\{\{p_{j,t}\}_{j=1}^{N}, s_t\}_{t=0}^{\infty}} \mathbb{E}\Bigg[\sum_{t=0}^{\infty}\beta^t\Bigg(& \underbrace{B\sum_{j=1}^{N}\left(p_{j,t}-p_{j,t}^{*}\right)^2}_{\textbf{loss from suboptimal prices}} + \underbrace{\theta\mathbf{1}_{\{\text{for any } j,\ p_{j,t}\neq p_{j,t-1}\}}}_{\textbf{cost of price changes}} \\ & + \underbrace{\psi\mathcal{I}\left(s_t;\{p_{j,t}^{*}\}_{j=1}^{N}|S^{t-1}\right)}_{\textbf{cost of information processing}}\Bigg)\Bigg|S^{-1}\Bigg] \qquad (2)\end{aligned}$$

$$\begin{aligned}\text{s.t.}\qquad & p_{j,t}^{*} = a_{j,t}+m_t, \quad \forall j=1,2,\cdots,N \\ & S^t = S^{t-1}\cup s_t \\ & S^{-1} \ \text{ is given}\end{aligned}$$

where $\mathbf{1}_{\{\text{for any } j,\ p_{j,t}\neq p_{j,t-1}\}}$ is an indicator function which is one if it changes any one of its prices.

Cost of Information Processing. The cost of information processing is linear in Shannon's mutual information function. Let $\mathcal{H}(X|Y)$ be a conditional entropy of a random variable of X given knowledge of Y. The firm's flow cost of information at time t is $\psi\mathcal{I}(s_t;\{p_{j,t}^{*}\}_{j=1}^{N}|S^{t-1})$, where

$$\mathcal{I}(s_t;\{p_{j,t}^{*}\}_{j=1}^{N}|S^{t-1}) = \mathcal{H}(\{p_{j,t}^{*}\}_{j=1}^{N}|S^{t-1}) - \mathbb{E}[\mathcal{H}(\{p_{j,t}^{*}\}_{j=1}^{N}|S^{t})|S^{t-1}]$$

is the reduction in uncertainty about its (frictionless) optimal prices that the firm experiences by observing the set of signals, s_t, given its prior information set, S^{t-1}, and ψ is the marginal cost of a

[28] Besides the existence of menu costs, this problem is different from the previous rational inattention models in LQG settings, such as Maćkowiak and Wiederholt (2015) or Pasten and Schoenle (2016), which solve the problem by assuming that the cost of information is not discounted and optimizing at the long-run steady-state for information structure. I assume that the agent discounts future costs of information at the same discount rate as their payoffs and solve the dynamic information acquisition problem. See, for instance, Afrouzi and Yang (2019), for the detailed discussion of solutions for dynamic rational inattention problem in LQG setups.

bit of information.

Let $z^a_{j,t} \equiv var(a_{j,t}|S^t)$ and $z^m_t \equiv var(m_t|S^t)$ be the firm's subjective uncertainty about the j-good specific shock and that about the aggregate shock, respectively. Then, I can rewrite the cost of information processing at time t in terms of $\{z^a_{j,t}\}_{j=1}^N$ and $z^m_t \equiv var(m_t|S^t)$:

$$\begin{aligned}\mathcal{I}\left(s_t; \{p^*_{j,t}\}_{j=1}^N | S^{t-1}\right) &= \sum_{j=1}^N \mathcal{I}\left(s^a_{j,t}; a_{j,t}|S^{t-1}\right) + \mathcal{I}\left(s^m_t; m_t|S^{t-1}\right) \\ &= \frac{1}{2}\left(\sum_{j=1}^N \log_2\left(\frac{z^a_{j,t-1}+\sigma^2_a}{z^a_{j,t}}\right) + \log_2\left(\frac{z^m_{t-1}+\sigma^2_m}{z^m_t}\right)\right)\end{aligned} \tag{3}$$

where $\{z^a_{j,-1}\}_{j=1}^N$ and z^m_{-1} are given. The first equality is followed from the fact that the underlying shocks are independent and the firm observes independent signals about them. The second equality holds since the firm observes Gaussian signals. Moreover, in this setup, I can rewrite the no-forgetting constraint, $S^t = S^{t-1} \cup s_t$, in terms of the firm's subjective uncertainty:

$$\begin{aligned}&0 \le z^a_{j,t} \le z^a_{j,t-1} + \sigma^2_a \;\text{ for }\; j = 1, 2, \cdots, N \\ &0 \le z^m_t \le z^m_{t-1} + \sigma^2_m.\end{aligned}$$

This reformulation shows that the cost of information processing is directly related to how much each firm reduces its subjective uncertainty about the good-specific shocks and that about the aggregate shock given their priors uncertainty about those shocks. If the marginal cost of information processing, ψ, is zero, the firm would like to choose zero subjective uncertainty about both underlying shocks. Since it is costly for the firm to reduce large amount of uncertainty about the underlying shocks when $\psi > 0$, it optimally chooses to observe less precise signals and to be optimally uncertain about the underlying shocks.

Recursive Formulation of the Firm's Problem. The loss from suboptimal prices can be decomposed into two components. Let $x_{j,t} = p_{j,t} - \mathbb{E}[p^*_{j,t}|S^t]$ be firm's *perceived* price gap about product j. Then,

$$\mathbb{E}\left[\left(p_{j,t} - p^*_{j,t}\right)^2 \Big| S^t\right] = \underbrace{z^a_{j,t} + z^m_t}_{\substack{\text{contemporaneous loss from} \\ \textbf{imperfect information}}} + \underbrace{x^2_{j,t}}_{\substack{\text{contemporaneous loss from} \\ \textbf{nominal rigidities}}} \tag{4}$$

where

$$
\begin{aligned}
z^a_{j,t} &= \mathbb{E}\left[\left(a_{j,t} - \mathbb{E}_t[a_{j,t}|S^t]\right)^2 \middle| S^t\right] \\
z^m_t &= \mathbb{E}\left[\left(m_t - \mathbb{E}_t[m_t|S^t]\right)^2 \middle| S^t\right]
\end{aligned}
$$

are subjective uncertainty about the j-good specific shock and that about the aggregate shock, respectively.

On the one hand, if there is no informational cost, $\psi = 0$, then the firm chooses to zero subjective uncertainty and thus there is no the contemporaneous loss from imperfect information. In this case, the firm's problem is identical to the problem in a standard menu cost model with multi-product firms. On the other hand, if there is no menu cost, $\theta = 0$, then the firm can always adjust its prices freely and thus will choose to zero *perceived* price gaps, $x_{j,t} = 0$ for all $j = 1, 2, \cdots, N$. In this case, the firm's problem is identical to the problem in a standard rational inattention model with multi-product firms. Notice that the perceived price gaps, $\{x_{j,t}\}$, are the firm's choice variables when it decides to change its prices. However, if the firm does not want to change its prices, then the perceived price gaps are stochastic variables which evolve according to

$$
\mathbf{x}_t \sim N(\mathbf{x}_{t-1}, \Sigma_t)
$$

where $\mathbf{x}_t = \{x_{1,t}, x_{2,t}, \cdots, x_{N,t}\}'$ and

$$
\Sigma_t(j,k) = \begin{cases} z^m_{t-1} + \sigma^2_m - z^m_t & \text{if } j \neq k \\ z^a_{j,t-1} + \sigma^2_a - z^a_{j,t} + z^m_{t-1} + \sigma^2_m - z^m_t & \text{if } j = k \end{cases} \tag{5}
$$

Now, given (3), (4), and (5), I reformulate the firm's problem (2) in a recursive form with $2N+1$ state variables:

$$
\begin{aligned}
V\left(\{x_{j,-1}\}^N_{j=1}, \{z^a_{j,-1}\}^N_{j=1}, z^m_{-1}\right) = \max_{\{\{z^a_j\}^N_{j=1}, z^m\}} \mathbb{E}\Bigg[& \max\left\{ V^I\left(\{x_j\}^N_{j=1}, \{z^a_j\}^N_{j=1}, z^m\right), V^C\left(\{z^a_j\}^N_{j=1}, z^m\right) \right\} \\
& - \frac{\psi}{2}\left(\sum_{j=1}^N \log\left(\frac{z^a_{j,-1} + \sigma^2_a}{z^a_j}\right) + \log\left(\frac{z^m_{-1} + \sigma^2_m}{z^m}\right)\right) \Bigg| S^{-1} \Bigg] \\
\text{s.t.} \qquad & 0 \leq z^a_j \leq z^a_{j,-1} + \sigma^2_a, \quad \forall j = 1, 2, \cdots, N \\
& 0 \leq z^m \leq z^m_{-1} + \sigma^2_m
\end{aligned}
$$

where

$$V^I\left(\{x_j\}_{j=1}^N,\{z_j^a\}_{j=1}^N,z^m\right)=-B\sum_{j=1}^N\left(x_j^2+z_j^a+z^m\right)+\beta V\left(\{x_j\}_{j=1}^N,\{z_j^a\}_{j=1}^N,z^m\right)$$

$$\text{with } \mathbf{x}\sim N\left(\mathbf{x}_{-1},\Sigma\right)$$

$$V^C\left(\{z_j^a\}_{j=1}^N,z^m\right)=\max_{\{y_j\}_{j=1}^N}-B\sum_{j=1}^N\left(y_j^2+z_j^a+z^m\right)-\theta+\beta V\left(\{y_j\}_{j=1}^N,\{z_j^a\}_{j=1}^N,z^m\right).$$

Here $V^I(\{x_j\}_{j=1}^N,\{z_j^a\}_{j=1}^N,z^m)$ represents the firm's value of not changing its prices. Similarly, $V^C(\{z_j^a\}_{j=1}^N,z^m)$ is the firm's value of changing its prices.

3.2 Decision Rules

In this section I describe key properties of the firm's optimal decision rules. First, because of the quadratic objective function and the symmetry of normal distribution, the value function is also symmetric around the null vector for the perceived price gaps. Second, given optimal choices of subjective uncertainty about the good-specific shocks ($\{z_{j,t}^a\}$) and that about the aggregate shock (z_t^m), the value function is decreasing in their absolute values of perceived price gaps. These two properties imply that given optimal choices of subjective uncertainty, the firm chooses to have zero perceived price gaps for all their goods whenever it decides to change its prices by paying the menu cost, θ. Then, the value function of the firm which changes its prices can be written:

$$V^C\left(\{z_j^a\}_{j=1}^N,z^m\right)=-B\sum_{j=1}^N\left(z_j^a+z^m\right)-\theta+\beta V\left(\{0\},\{z_j^a\}_{j=1}^N,z^m\right).$$

Given the non-convex cost of price changes, the firm's pricing decision follows a so-called S-s rule which is a standard feature in a menu cost model. There are inaction bands such that if the sum of *perceived* price gaps is outside of the inaction bands, the firm pays the menu cost and changes its prices. If the firm believes that the sum of the squares of its perceived price gaps is not far from the optimal level (which is zero in this model) and thus is within the inaction bands, the firm does not change its prices and waits for the next period. As it will be clear in later, the inaction bands depend on the firm's optimal information decisions while those are constant without informational costs.

Since the firm's problem is a non-convex optimization problem in its pricing decision and there are occasionally binding no-forgetting constraints for its choices of subjective uncertainty, this problem should be solved numerically. I solve two models using a method of value function iterations: a single-product firm model and a two-product firm model. To understand how the optimal information choices of a rationally inattentive firms are affected by the given menu costs, I first characterize the single-product firm's optimal information choices and pricing decisions with and without the informational costs. Then, I show how the information choices and price setting decisions of a multi-product firm differ from those of a single-product firm.

3.2.1 A Single-Product Firm

I first consider a single-product firm's optimal decision rules. Here I drop the j-index because the firm only produces one product.

Optimal Information Acquisition. A single-product firm's optimal policy functions for subjective uncertainty about the good-specific shock are presented in Figure 3. Given the firm's prior subjective uncertainty (z_{t-1}^a), the firm's posterior uncertainty (z_t^a) is high if its price is close to the perceived optimal price. In particular, the right panel of Figure 3 shows that if the firm's prior uncertainty is low and its prior price gap is around zero, then the no-forgetting constraint is binding and the firm does not acquire new information about the shock. The amounts of information acquisition are increasing both in their prior subjective uncertainty (z_{t-1}^a), and in their absolute value of prior price gaps ($|x_{t-1}|$). This implies that when the firm believes that its price gap is close to the inaction bands, the firm wants to acquire a large amount of information. This is because potential losses from mistakes in their pricing decisions are large if the firm thinks its price is far way from its optimal level; it could make wrong decisions either by paying the menu cost and changing the price when it was not supposed to do or by choosing not to change its price when it should do.

Pricing Decision Given the Optimal Information Choices. After choosing the optimal subjective uncertainty about the underlying shock, the firm decides whether to change its price or not given the new information set. The firm's pricing decision follows the S-s rule which is a standard feature in a menu cost model. The main difference of the S-s rule in this model from that in the standard menu cost model is that the inaction bands are time-varying (see the upper right panel of Figure 5). Formally, let $\hat{x}_t$ be a posterior of the perceived price gap after observing the time t optimal signals. Then,

$$\begin{aligned}\hat{x}_t &= p_t - \mathbb{E}[p_t^*|S^t] = p_{t-1} - \mathbb{E}[a_t + m_t|S^t] \\ &= x_{t-1} - \{\mathcal{K}_t^a(s_t^a - \mathbb{E}[a_t|S^{t-1}]) + \mathcal{K}_t^m(s_t^m - \mathbb{E}[m_t|S^{t-1}])\}\end{aligned}$$

where $\mathcal{K}_t^a$ and $\mathcal{K}_t^m$ are the optimal Kalman gains for the good-specific shock and for the aggregate shock, respectively. Given subjective uncertainty, z^a and z^m, there exists $\tilde{x}(z^a, z^m) \geq 0$ such that

$$-\tilde{x}_t(z_t^a, z_t^m)^2 + \beta V\left(\tilde{x}_t(z_t^a, z_t^m), z_t^a, z_t^m\right) = -\theta + \beta V\left(0, z_t^a, z_t^m\right).$$

The firm will change its price if $|\hat{x}_t| > \tilde{x}_t(z_t^a, z_t^m)$. Then, the perceived price gap at the end of period t, x_t, is

$$x_t = \begin{cases} \hat{x}_t & \text{if } |\hat{x}_t| \leq \tilde{x}_t(z_t^a, z_t^m) \\ 0 & \text{if } |\hat{x}_t| > \tilde{x}_t(z_t^a, z_t^m). \end{cases}$$

Figure 4 shows the inaction bands, $\tilde{x}_t(\cdot, z_t^m)$, for the various values of z_t^m. The inaction bands in a myopic model, where $\beta = 0$, are constant since the firm's subjective uncertainty is no longer state variables for the firm's problem. If $\beta > 0$, the inaction bands depend on the firm's subjective uncertainty. When the firm is more uncertainty about the underlying shocks, the inaction bands are wider. This makes sense since when the firm is uncertain about its true optimal price, it is reluctant to take an action by changing its price. As shown in Figure 5, this makes the firm change its price when subjective uncertainty is low.

The main implication of this interaction between information acquisition and pricing decisions is that the firm is likely to be more informed about the underlying shocks when it changes its price than when it does not.[29] For example, the simulation result shows that the average Kalman gain is 0.56 when the firm changes its price, while it is only 0.22 when it does not change its price. If we consider an economy with many rationally inattentive firms that face the menu cost, which I consider in the next section, price adjusters will be more informed about the economy than price non-adjusters. I call this force *selection in information processing*. This selection in information processing plays a key role in explaining the monetary non-neutrality in the general equilibrium model that I will explore in the next section.

Another interesting characteristic of the firm's pricing rule is that the firm makes mistakes in both intensive and extensive margins. Since the firm's pricing decision is based on its *belief* about

[29] Models with both menu costs and observational costs in Alvarez et al. (2011) or Bonomo et al. (2019b) also have the same implication. In these models, a firm has to pay a fixed cost to acquire full-information about the underlying shocks and can change its price by paying a fixed menu cost. Optimal pricing rule implies that the firm only changes its price when it pays the observational cost. This is an extreme case in a sense that the firm has full information when it changes its price while it acquires no information when it does not. Gorodnichenko (2008) also shows that firms have an incentive to buy an additional signal prior to changing prices in a model with menu costs and endogenous information choices.

the price gap ($p_t - \mathbb{E}[p_t^*|S^t]$) rather than the *true* price gap ($p_t - p_t^*$), the firm changes its price by wrong amounts when it decides to change. Moreover, it makes mistakes on the timing of its price changes: the firm changes its price when it was not supposed to do, or it does not change the price when it should do. For example, Figure 5 shows that at period 20, the firm decreases its price when the true price gap (a red dashed line) is within the inaction band. Also, at period 30, the firm does not change its price while the true price gap is outside of the inaction band.

3.2.2 A Two-Product Firm

Now I consider a two-product firm's optimal decisions over time. The two-product firm shares the same characteristics about their optimal decisions rules with the single-product firm that I discussed above. However, on top of that, two interesting economies of scope motives emerge in the two-product firm's optimal choices. One is economies of scope in price changes through the menu cost technology, and the other is economies of scope in information processing through the rational inattention.

Economies of Scope in Price Changes. Figure 6 shows simulation results of a two-product firm. Like a single-product firm, the inaction bands of the two-product firm also depend on its subjective uncertainty. The main difference in the two-product firm's pricing decision is that the price changes of one of its products depends on the perceived price gap of the other product. For example, the right upper and lower panels of Figure 6 show that when the perceived price gap of product 2 is large, the inaction bands for product 1 is narrow. This implies that the timing of its price changes within the firm is synchronized and, more importantly there are both large and small price changes. This is called economies of scope in price changes from the menu cost technology: if the firm decides to pay the menu cost to change one of its prices, then the price changes of additional products are free for the firm. This implies that given the same size of menu cost, the multi-product firm is likely to change its prices more frequently than the single-product firm. Moreover, since the additional price changes are free and thus there are many small price changes, the multi-product firm changes its prices on average by smaller amounts than the single-product firm. These implications are consistent with my empirical findings in the previous section.

Economies of Scope in Information Processing. In the two-product model, there is another scope motive called economies of scope in information processing. Given the same informational cost, the two-product firm is more informed about the aggregate shock than a single-product firm.

Since the firm's optimal prices for all goods are affected by the aggregate shock, the value of information about the aggregate shock will be higher if the firm produces more products. This relationship is clearly shown if there is no menu cost ($\theta = 0$) in the model. In this case, the firm's optimal subjective uncertainty about the aggregate shock satisfies the following FOC:

$$B \cdot N = \frac{\psi}{2 \log 2} \left(\frac{1}{z_t^m} - \beta \frac{1}{z_t^m + \sigma_m^2} \right) \tag{6}$$

where z_t^m is decreasing in the number of products, N. The economies of scope motive in information processing is also in there with the menu cost ($\theta > 0$). For example, the average subjective uncertainty about the aggregate shock for the two-product firm is 25% smaller than that for the single-product firm. This implication is consistent with my empirical finding that the firms' backcast errors about the aggregate inflation decrease in the number of products they produce. Since the multi-product firms are more informed about the aggregate shock than the single-product firms, they will be more correct and faster to learn about the monetary policy shocks. Thus, this scope motive in information processing will reduce the monetary non-neutrality that I will show in the next section.

4 A Dynamic General Equilibrium Model

In this section, I consider a dynamic general equilibrium model with both menu costs and rational inattention frictions for firm side. The economy is populated by a representative household and a unit measure of monopolistically competitive firms. Each firm sells N products. I discuss the problem of the representative household, and that of the firms, and then define an equilibrium for this economy.

After I define the model with an arbitrary number of products, I simulate two model economies: one with single-product firms and the other with two-product firms. I calibrate the model economies to match the three key statistics that I observe in the data: the frequency and the size of price changes, and the elasticity of backcast errors with respect to the number of products. The goals of this section are to characterize the stationary distribution of price changes and that of firms' subjective uncertainty in both models and to study the implications for monetary non-neutrality. This characterization is essential to understand how a monetary policy shock can affect in the model economy with both menu costs and rational inattention.

I first consider my baseline menu costs economy with rationally inattentive single-product firms to highlight how the interaction between endogenous information acquisition and menu costs technology affects to the distribution of desired price changes. As I showed in the previous section, this interaction generates *selection in information processing* where price adjusters are more informed about underlying shocks than price non-adjusters. I show that this selection effect in information processing about the idiosyncratic good-specific shocks endogenizes a *leptokurtic* distribution of firms' perceived price gap even though all exogenous disturbances in the model are Gaussian. This endogenous leptokurtic distribution weakens *selection effect of price changes*, which is a strong force in reducing the real effects of monetary policy shocks in a only menu cost model. This implies that this selection in information processing, which is coming from the interaction between nominal and informational rigidities, will amplify the real effects of monetary policy shocks.

On the other hand, selection in information processing about the aggregate shock has different implications for the monetary non-neutrality. Since the price adjusters are more informed about the monetary policy shock than the price non-adjusters, the average response of price level in this economy with selection in information processing will be larger than that in the other economy where all firms have the same information about the underlying shocks. This force reduces the real effects of monetary policy shocks.

Then, I compare the two-product baseline model with the single-product model to show the economies of scope motives both in price changes and in information processing. In the calibrated two-product model, there are many small price changes as well as large price changes. Also, I find that the average Kalman gains on the signal about the aggregate shock in the two-product model are larger than those in the single-product model. These imply that both economies of scope motives are in there in the calibrated general equilibrium model.

Finally, I implement impulse response analysis to a monetary policy shock in the calibrated baseline models. I show that monetary non-neutrality in the baseline model with single-product firms is nearly as large as that in the Calvo sticky price model, while it decreases in the two-product baseline model. I discuss main mechanisms behind these results.

4.1 Environment

Households. Time is discrete and the representative household lives an infinite horizon. The household seeks to maximize the expected discounted sum of period utility. The discount factor is $\beta \in (0, 1)$.

The representative household's problem is

$$\max_{\{\{C_{i,j,t}\}_{j=1}^{N}, C_t, L_t, B_t\}_{t\geq 0}} \mathbb{E}_0^f \left[\sum_{t=0}^{\infty} \beta^t (\log C_t - L_t)\right] \tag{7}$$

subject to

$$\int \sum_{j=1}^{N} P_{i,j,t} C_{i,j,t} di + B_t \leq R_{t-1} B_{t-1} + W_t L_t + \Pi_t, \quad \text{for all } t$$

where

$$C_t = \left(\frac{1}{N}\sum_{j=1}^{N} C_{j,t}^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \quad C_{j,t} = \left(\int C_{i,j,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Here $\mathbb{E}_t^f [\cdot]$ is the full information rational expectation operator at time t. Since the main purpose of this paper is to study the effects of nominal rigidity and rational inattention among firms, I assume that the household is fully informed about all prices and wages. L_t is the labor supply of the household, B_t is the demand for nominal bond, R_{t-1} is the nominal interest rate, W_t is the nominal wage, and Π_t is the aggregate profit from the firms. Also, C_t is the aggregator over the consumption for differentiated goods, $C_{j,t}$ is an aggregator over the consumption of good j, and ε is the constant elasticity of substitution across different firms that produce the same good and γ is the constant elasticity of substitution across different goods.

The above formulation implies that demand for an individual variety is

$$C_{i,j,t} = \left(\frac{P_{i,j,t}}{P_{j,t}}\right)^{-\varepsilon} \left(\frac{P_{j,t}}{P_t}\right)^{-\gamma} C_t$$

where P_t is the price of aggregate consumption bundle C_t, and $P_{j,t}$ is the price of good j. These prices are given by

$$P_t = \left(\frac{1}{N}\sum_{j=1}^{N} P_{j,t}^{1-\gamma}\right)^{\frac{1}{1-\gamma}}, \quad P_{j,t} = \left(\int_0^1 (P_{i,j,t})^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}.$$

Let $M_t \equiv P_t C_t$ be the aggregate nominal demand for the economy. Then, the household's optimal choices about aggregate consumption and labor supply satisfy the following first-order conditions:

$$P_t C_t = W_t = M_t$$
$$1 = \beta R_t \mathbb{E}_t^f \left[\frac{M_t}{M_{t+1}} \right],$$

with a standard transversality condition. The log-utility implies that the intertemporal optimal condition relates the nominal interest rate to the law of motion of the aggregate demand. This enables us to formulate monetary policy in terms either of the nominal interest rates or the aggregate nominal demand. Moreover, the linear disutility in labor ensures that the nominal wage is proportional to the nominal aggregate demand. This closely follows Golosov and Lucas (2007) and Midrigan (2011) and ensures that shocks to the nominal demand translate one-for-one into changes in the firms' nominal marginal cost, which I will discuss in the firms' problem.

Firms. There is a measure one of firms, index by i, who operate in monopolistically competitive markets. Each firm produces N goods, indexed by j. Firms take wages and demands for their goods as given, and choose their prices $\{P_{i,j,t}\}_{j=1}^N$ based on their information set, S_i^t, at that time. Given the set of previous prices, $\{P_{i,j,t-1}\}_{j=1}^N$, firms can change all their prices by paying a fixed menu cost, θ. After setting their prices, firms then hire labor from a competitive labor market and produce the realized level of demands that their prices induce using with a production function,

$$Y_{i,j,t} = \frac{1}{A_{i,j,t}} L_{i,j,t}.$$

where $A_{i,j,t}$ is an idiosyncratic good j-specific productivity shock and $L_{i,j,t}$ is a demand for labor for producing good j. I define the firm i's markup for good j as $\mu_{i,j,t} = \frac{P_{i,j,t}}{W_t A_{i,j,t}}$. Using the demand function for each good and market clearing conditions ($Y_{i,j,t} = C_{i,j,t}$, $\forall$ j), the firm i's nominal flow profit at time t can be written as a function of markups:

$$\begin{aligned}\Pi_{i,t} &= \sum_{j=1}^N \left(P_{i,j,t} - W_t A_{i,j,t}\right) Y_{i,j,t} \\ &= \sum_{j=1}^N \left(\mu_{i,j,t} - 1\right) \left(\mu_{i,j,t}\right)^{-\varepsilon} \left(W_t A_{i,j,t}\right)^{1-\varepsilon} \left(P_{j,t}\right)^{\varepsilon-\gamma} \left(P_t\right)^{\gamma} Y_t\end{aligned}$$

where Y_t is the nominal aggregate demand. Let $p_{i,j,t}^* = \log(W_t) + \log(A_{i,j,t})$ be the log deviation of (frictionless) optimal price of good j from its non-stochastic steady state. Then, we define firm

i's true price gap of good j as

$$\hat{\mu}_{i,j,t} = p_{i,j,t} - p^*_{i,j,t}$$

where $p_{i,j,t}$ is the log deviation of the price of good j from its non-stochastic steady state.[30] Then, a second order approximation of the profit function gives a quadratic form in the true price gap,

$$\Pi_{i,t}(\{\hat{\mu}_{i,j,t}\}_{j=1}^N) = C - B\sum_{j=1}^N \hat{\mu}^2_{i,j,t},$$

where C is a constant and $B = \frac{\varepsilon-1}{2}$ is a slope of profit curve.[31]

Firms are rationally inattentive. At the beginning of period t, firm i takes its initial information set, S_i^{t-1}, as given and chooses a set of optimal signals, $s_{i,t}$, subject to a cost of information processing, $\psi\mathcal{I}(s_{i,t};\{p^*_{i,j,t}\}_{j=1}^N|S_i^{t-1})$, where ψ is a marginal cost of a bit of information and $\mathcal{I}(\cdot)$ is a Shannon's mutual information function. It then forms a new information set, $S_i^t = S_i^{t-1}\cup s_{i,t}$, and sets its new prices, $\{p_{i,j,t}\}_{j=1}^N$, based on that. The firm pays a menu cost, θ, if it decides to change any prices. Otherwise, the firm waits for the next period.

Formally, after taking a quadratic approximation of firm i's profit function around non-stochastic steady state and deriving a loss function from the suboptimal prices, the firm's problem can be written as:

$$\begin{aligned} \min_{\{\{p_{i,j,t}\}_{j=1}^N, s_{i,t}\}_{t\geq 0}} \quad & \mathbb{E}\left[\sum_{t=0}^{\infty}\beta^t\left\{B\sum_{j=1}^N (p_{i,j,t}-p^*_{i,j,t})^2 + \theta\mathbf{1}_{\{\text{for any } j,\ p_{i,j,t}\neq p_{i,j,t-1}\}}\right.\right. \\ & \left.\left.\qquad + \psi\mathcal{I}(s_{i,t};\{p^*_{i,j,t}\}_{j=1}^N|S_i^{t-1})\right\}\middle| S_i^{-1}\right] \qquad (8) \\ \text{s.t.} \quad & p^*_{i,j,t} = \log(A_{i,j,t}) + \log(W_t), \quad j = 1,2,\cdots,N \\ & S_i^t = S_i^{t-1}\cup s_{i,t} \end{aligned}$$

Productivity, Monetary Policy, and Sets of Available Signals. Firm i's log productivity of j good, $a_{i,j,t}\equiv\log A_{i,j,t}$, evolves according to a random walk process:

$$a_{i,j,t} = a_{i,j,t-1} + \varepsilon^a_{i,j,t}, \quad \varepsilon^a_{i,j,t}\sim N(0,\sigma_a^2)$$

[30]The true price gap $\hat{\mu}_{i,j,t}$ can be also written as a markuk gap, $\hat{\mu}_{i,j,t} = \log(\mu_{i,j,t}/\mu_j^*)$, which is a the log deviation of the current markup to the non-stochastic steady state markup $\mu_j^* = \frac{\varepsilon}{\varepsilon-1}$.

[31]See Appendix A for the detailed derivation.

where $\varepsilon^a_{i,j,t}$ is independent across firms and across goods.

For simplicity, I assume that the monetary policy is set in terms of the aggregate demand. The log of aggregate demand, $m_t \equiv \log(M_t)$, follows a random walk process:

$$m_t = m_{t-1} + \varepsilon^m_t, \quad \varepsilon^m_t \sim N(0, \sigma^2_m) \tag{9}$$

where ε^m_t is an independently and identically distributed normal disturbance.

As discussed in the firms' problem, firms are rationally inattentive. Given its initial information set, S_i^{t-1}, at time t, firm i chooses a set of optimal signals about both the idiosyncratic good-specific shocks and the monetary shock from the following sets of available signals:

$$\begin{aligned}
\mathcal{S}^a_{i,j,t} &= \{a_{i,j,t} + \eta^a_{i,j,t}\xi^a_{i,j,t} : \eta^a_{i,j,t} \geq 0,\ \xi^a_{i,j,t} \sim N(0,1)\}, \text{ for } j = 1, 2, \cdots, N \\
\mathcal{S}^m_{i,t} &= \{m_t + \eta^m_{i,t}\xi^m_{i,t} : \eta^m_{i,t} \geq 0,\ \xi^m_{i,t} \sim N(0,1)\}
\end{aligned}$$

Here, rational inattention errors, $\xi^a_{i,j,t}$ and $\xi^m_{i,t}$, are independent across firms. At each time t, given S^{t-1}, firm i chooses its optimal signals $s^a_{i,j,t} \in \mathcal{S}^a_{i,j,t}$ for $j = 1, 2, \cdots, N$, and $s^m_{i,t} \in \mathcal{S}^m_{i,t}$ subject to the cost of information processing. Then, the firm's new information set evolves as $S_i^t = S_i^{t-1} \cup s_{i,t}$ where $s_{i,t} = \{\{s^a_{i,j,t}\}_{j=1}^N, s^m_{i,t}\}$.

Definition of Equilibrium. Given exogenous stochastic processes for idiosyncratic good-specific productivity shocks $\{\{\{a_{i,j,t}\}_{j=1}^N\}_{i\in[0,1]}\}_{t\geq 0}$, a general equilibrium of the economy consists of an allocation for the representative household,

$$\Omega^H = \left\{C_t, \{C_{i,j,t}\}_{j=1}^N, L_t, B_t\right\}_{t\geq 0},$$

an allocation for every firm $i \in [0,1]$ given the initial set of signals,

$$\Omega^F_i = \left\{\{s^a_{i,j,t} \in \mathcal{S}^a_{i,j,t}\}_{j=1}^N, s^m_{i,t} \in \mathcal{S}^m_{i,t}, \{p_{i,j,t}, L_{i,j,t}, Y_{i,j,t}\}_{j=1}^N\right\}_{t\geq 0},$$

and a set of prices $\left\{\{P_{j,t}\}_{j=1}^N, P_t, R_t, W_t\right\}_{t\geq 0}$ such that

1. given the set of prices and $\{\Omega^F_i\}_{i\in[0,1]}$, the household's allocation solves its problem as specified in Equation (7)

2. given the set of prices and Ω^H, and the implied labor supply and output demand, firms allocation solve their problem as specified in Equation (8)

3. given the set of prices, Ω^H, and $\{\Omega_i^F\}_{i\in[0,1]}$, $\{M_t \equiv P_tC_t\}_{t\geq 0}$ satisfies the monetary policy rule specified in Equation (9)

4. and all markets clear: for all $t \geq 0$,

$$
\begin{aligned}
Y_{i,j,t} =& C_{i,j,t}, \qquad \text{for all } i \in [0,1] \text{ and } j = 1, 2, \cdots, N \\
L_t =& \int \left(\sum_{j=1}^{N} L_{i,j,t} \right) di \\
B_t =& 0.
\end{aligned}
$$

4.2 Calibration and Parameterization

In the numerical exercises, I compare two economies with $N = 1$ and $N = 2$.[32] I set the monthly discount factor to $\beta = 0.96^{(1/12)}$, which implies a real interest rate of 4 percent. I set the elasticity of substitution across firms to be four ($\varepsilon = 4$) which matches the firms' average markup of 33% in the survey data.[33] Moreover, I assume the elasticity of substitution between goods is the same as that across firms ($\gamma = 4$). However, the value of γ plays little role since there are no common good-specific shocks in the model.

I calibrate the standard deviation of the log difference in nominal demand, σ_m, to match the standard deviation of the growth rate of nominal GDP in New Zealand, 0.0065.[34] There are three key model parameters which should be calibrated: the size of menu costs (θ), the size of marginal costs of information processing (ψ), and the size of idiosyncratic good-specific shocks (σ_a). I assume that the marginal cost of processing a bit of information in both models are the same.[35] I calibrate those three parameters to match the median frequency of price changes (once a year), the median size of absolute price changes (6.5%), and slope of backcast errors about the growth rate of aggregate nominal GDP on the number of products (-0.026) observed in the survey data.[36]

[32]Since the number of state variables are increasing linearly in the number of products as $2N + 1$, a model with more than two-product is hard to solve. A two-product economy is also considered as a baseline in Midrigan (2011) and Karadi and Reiff (2019). Moreover, in the New Zealand survey data, the average of main product's share of total output value is about 60% excluding single-product firms. This implies that a two-product firm is a good benchmark for a multi-product firm. In Section 5.1, I solve models with any arbitrary number of products under some simplifying assumptions.

[33]This value is a middle of 3 and 7, the respective elasticity of substitution parameters by Midrigan (2011) and Golosov and Lucas (2007). It directly affects the slope of profit curves, and thus the estimates of menu costs and the standard deviation of good-specific shocks without altering main findings.

[34]I restrict the sample to post 1991 New Zealand data since New Zealand has explicitly conducted monetary policy by targeting inflation in that time period.

[35]As shown in Pasten and Schoenle (2016), an alternative assumption for cost of information processing, such as a constant loss per good from imperfect information, does not change the main findings in this paper.

[36]Parker (2017) also finds the median frequency of price changes is once a year in New Zealand using *2010 Business*

The latter is obtained by regressing the firms' backcast errors about the growth rate of nominal GDP on firms' number of products.[37] The estimate shows that controlling for firm and manager characteristics as well as industry controls, the backcast errors decrease by 0.026 percentage points when firms produce one more good.[38] The model counterpart measure is calculated by taking difference between average backcast errors about the growth rate of nominal demand in single- and two-product models. The three moments exactly identify the three key model parameters, and as the Table 5 shows, all the targeted moments are well matched.

Table 6 shows the calibrated and assigned parameters in both single-product and two-product models. The baseline parameterization implies a menu cost of 0.93 percent of steady-state (per good) revenue in the single-product model. Given the average frequency of price changes, the overall cost of price adjustment in the single-product model is around 0.078 percent of steady-state revenue. Similarly, the overall cost of price adjustment in the two-product model is around 0.071 percent of steady-state revenue. These values are smaller than estimates in the previous literature, which often used U.S. data, since the average size of absolute price changes in New Zealand is small.[39] The calibrated standard deviations of the idiosyncratic good-specific shocks are around 2 percent per month in both models, which are about three times bigger than the standard deviation of the monetary policy shock. The calibrated marginal cost of information processing is 0.7 percent of steady-state (per good) revenue. This value implies about 0.2 of an average Kalman gains on the signal about the idiosyncratic shocks in both model (see Table 7). This is equivalent to a quarterly gain of 0.38, which is close to the estimate of 0.45 in Coibion and Gorodnichenko (2015), which uses the U.S. Survey of Professional Forecasters data.

4.3 Simulation

In this section, I show the simulation results for two models with a large number of firms facing both idiosyncratic good-specific shocks and the monetary policy shock.[40] I show that the two-product model has a more realistic distribution of price changes compared to the single-product

Operations Survey data carried out by Statistics New Zealand while the data does not provide a quantitative measure of price changes.

[37]The backcast errors about nominal GDP growth rate are from Wave #4 of the survey. In the survey, firms' managers are asked about the current inflation and the real GDP growth rate in New Zealand. I take a summation of both measures to obtain firms' perceived growth rate of nominal GDP in the economy.

[38]See Table A.5 in appendix for the regressions results with and without controls.

[39]For example, Levy et al. (1997) find menu costs of 0.7 percent of revenue, while Zbaracki et al. (2004) find price adjustment costs as large as 1.2 percent. Stella (2018) estimates the total cost of changing prices between 0.3% and 1.3% of revenues. Moreover, The baseline calibration in Midrigan (2011) implies a menu cost of 0.34 percent of revenue while it is 0.15 percent of revenue in Karadi and Reiff (2019).

[40]A simulation algorithm for two-product model is presented in Appendix B.

model by generating both large and small price changes. Also, I emphasize two distributional characteristics that will be important to understand how big are the real effects of the monetary shocks in both models, which I extensively investigate in the next section. First, there is a selection in information processing; price-adjusters are having better information about both idiosyncratic and aggregate shocks than price non-adjusters. In particular, I show that selection in information processing about idiosyncratic shocks endogenizes a leptokurtic distribution of desired price changes, which acts as a force to weaken selection effects of price changes. Second, the multi-product firms value more on the information about the monetary policy shock than the single-product firms.

Distribution of Price Changes. Figure 7 shows a distribution of price changes in the single-product model and that in a two-product model. As a comparison, I also plot the distribution of price changes in the only menu cost model with single-product firms (yellow bar). All three models are calibrated to match the same frequency and size of price changes. In the baseline single-product model (blue bar), there are no small price changes since price changes occur when firms believe that their price is outside of its inaction bands. However, the Kurtosis of the distribution in the baseline single-product model is higher than that in the only menu cost model and there are relatively small fraction of firms around the inaction bands in the baseline model compared to the only menu cost model.[41] Notice that firms in the baseline model have different inaction bands depending on their subjective uncertainty while firms in the only menu cost model have the same inaction bands (black vertical line). The heterogeneity in firms' subjective uncertainty makes the distribution of price changes in the baseline model be more dispersed than that in the only menu cost model.

In contrast to the single-product models, the baseline two-product model generates both small and large price changes. This is because of economies of scope in menu cost technology; when a two-product firm believes that one of its price are far away from its perceived optimal price, the firm pays a fixed menu cost to change its price. Since the additional price changes are free after paying this menu cost, the firm also changes the price of the other product even if it is still very close to the perceived optimal price. Thus the economy with two-product firms can have a large fraction of small price changes and a higher kurtosis of price changes.[42] This economies of scope

[41] The red vertical lines are the average of inaction bands across all firms in the baseline single-product model. Since I calibrate both models to have the same frequency and size of price changes, the average inaction bands in both models are very similar.

[42] A only menu cost model with two-product firms also can make small price changes through the same economies of scope motive (e.g. Midrigan (2011); Alvarez and Lippi (2014)). However, the baseline two-product model has a

in menu cost technology weakens selection effects of price changes, which act as a strong force to reduce monetary non-neutrality in a standard menu cost model such as Golosov and Lucas (2007).

Selection in Information Processing and Endogenous Leptokurtic Distribution of Price Gaps. Table 7 shows another important characteristics about firms' optimal information choices. The second and third row compare the average Kalman gains of firms that adjust their prices to those of firms that do not adjust their prices. The Kalman gains represent how much firms put their weight on the new information relative to their prior estimates. When firms' signals are perfectly telling about the true underlying shocks, the Kalman gain is one; while in this model firms optimally choose not to be perfectly informed about the shocks due to the cost of information, the Kalman gain is less than one. Thus, the average Kalman gains can be interpreted as the average degree of firms' attentiveness to shocks in this model. I find that there is a selection in information processing; price adjusters are more informed about both idiosyncratic and aggregate shocks than price non-adjusters. The price adjusters' average Kalman gains in the signals about idiosyncratic shocks are about three times bigger than those of price non-adjusters. As shown in Figure A.2 in Appendix, the distributions of price adjusters' subjective uncertainty about both shocks are more concentrated than that of price non-adjusters' subjective uncertainty. The price adjusters also put more weight on new information about the aggregate shock than price non-adjusters. These findings are true in both the single- and the two-product models, implying that selection in information processing operates regardless of the number of products in the model.

This selection in information processing is due to the interaction between firms optimal information and pricing decisions. As shown in the previous section, firms' optimal information acquisition policy is affected by their belief about their price gaps. If a firm believes that its price is far away from its optimal level and close to the inaction bands, the potential losses from mistakes in pricing decisions would be very large. This makes the firm process more information about the shocks to reduce the losses. After the realization of shocks, this firm is more likely to be a price adjuster since its prior price gap is close to the inaction bands. For this reason, on average, the price adjusters in the economy are better informed about the underlying shocks than the price non-adjusters.

This new selection mechanism in information processing about the idiosyncratic shocks has an important implication about the distribution of desired price changes: it *endogenously* gener-

more dispersed distribution of price changes than the only menu cost model with two-product firms since, again, firms' optimal inaction bands are a function of their subjective uncertainty in the baseline model. Figure A.3 shows a comparison of the distributions of price changes in the baseline two-product model with that in the only menu cost model with two-product firms.

ates a leptokurtic distribution of firms' perceived desired price changes.[43] Figure 8 shows the distributions of the perceived and true price gaps in the single-product model. First, the blue line is a prior distribution about firms' perceived price gap. At the beginning of period, all firms believe that their prices are within their inaction bands and there is a lot of zero perceived price gaps, which were adjusted at the previous period. This implies that the *prior* distribution of firms' perceived price gaps is very concentrated around zero and has a high Kurtosis. After being hit by Gaussian idiosyncratic shocks, the distribution of true price gaps in the economy is Gaussian (red dashed line). If firms have perfect information about their true optimal prices, their pricing decisions would be based on their true price gaps. Since the distribution of the true price gaps is Gaussian, as in the standard single-product menu cost model, there would be large selection effects of price changes: an expansionary monetary shock triggers a lot of large price increases, it offset a mass of large price decreases.

However, in the model with both menu costs and informational costs, firms are rationally inattentive about their true optimal prices. Firms all choose their optimal Gaussian signals and update their estimates of price gaps, but they do not do so in the same way. Firms which think that their price gap is well-within their inaction bands and who think it is unlikely that they will need to change prices have little incentive to collect much new information: they choose to remain quite uninformed and update the estimates of their price gaps with a large weight on their (imprecise) priors. In contrast, firms that think they are close to the boundaries of their inaction regions have a high incentive to collect information and therefore choose to become more informed. Since the distribution of priors of firms' perceived price gaps is very concentrated around zero, this selection in information processing makes the distribution of posteriors of the perceived price gaps also *leptokurtic*. This implies a small selection effects of price changes in my baseline model because the rationally inattentive firms' pricing decisions are based on their posterior of perceived price gaps. Thus, the endogenous leptokurtic distribution will act as a strong force to amplify monetary non-neutrality in the general equilibrium model that I show in the following subsection. Previous studies of standard menu cost models often assume exogenously the leptokurtic distribution of idiosyncratic shocks to weaken selection effects of price change (e.g. Gertler and Leahy (2008); Midrigan (2011); Vavra (2013); Karadi and Reiff (2019); Baley and Blanco (2019)). Unlike these studies, due to selection in information processing about the idiosyncratic shocks, my baseline model with both rational inattention and menu costs can generate the leptokurtic distribution

[43] If a firm has a price gap of x % and it is free to change its price, then it would change by $-x$%. I use "price gaps" and "desired price changes" interchangeably.

endogenously even if the distribution of underlying shocks is Gaussian.[44]

Value of Information about the Aggregate Shock. Given both idiosyncratic shocks and aggregate shocks, which shocks do firms pay more attention to? Maćkowiak and Wiederholt (2009) show that rationally inattentive firms process more information about an idiosyncratic shock rather than an aggregate shock since the former is more volatile than the latter. Optimal attention allocation in the rational inattention model implies that firms have a large incentive to allocation their attention in more volatile shocks. This is also true in the the current models with single- and two-product firms. The first row of Table 7 shows in both single- and two-product models, the average Kalman gains across all firms for the idiosyncratic shocks are lager than those for the aggregate shock since the idiosyncratic shocks are more volatile than the aggregate shock.

However, the amount of information processing about the aggregate shock is different in the single- and the two-produce model. As I document in the previous section, the value of information about the aggregate shock is higher for the two-product firms than the single-product firms since the firms' frictionless optimal prices for all goods are affected by the aggregate shock. Table 7 shows that the two-product firms are more informed about the aggregate shocks than the single-product firms. The Kalman gains for aggregates shocks are about twice in the two-product model than in the single-product model. This implies that firms in the two-product economy will be more responsive to the monetary policy shock than firms in the single-product economy as they are more informed about it.

4.4 Real Effects of Monetary Policy Shocks

In this subsection, I show that monetary non-neutrality in the baseline model with single-product firms is nearly as large as that in the Calvo sticky price model, while it decreases in the two-product baseline model. To show this, I take the calibrated models and hit them with one standard deviation shock to monetary policy disturbances. Figure 9 shows the impulse responses of output in the single- and the two-product models. I also show the impulse responses in the standard menu cost model with single product firms and that in the Calvo sticky price model.

The output response to an one standard deviation monetary policy shock in the standard menu cost model is small and short-lived. The half-life of output response is only 2 months. This is well-known fact that in this model, there are large selection effects of price changes, which act as a

[44]This endogenous leptokurtic distribution of perceived price gaps is also presented in the two-product model as shown in Figure A.4 in appendix.

strong force to reduce the monetary non-neutrality (e.g. Golosov and Lucas (2007)). In the baseline single-product model with both menu costs and rational inattention however, the real effects of monetary policy shocks are large. The impact response increases by 60% and cumulative output responses, which is defined as an area under the impulse responses of output, are about seven times bigger than that in the standard menu cost model. In fact, this large real effects are comparable to those in the Calvo sticky price model. However, the large real effects are reduced in the two-product baseline model. The cumulative output responses in the two-product model is 20% smaller than those in the one-product model, and the half-life of output responses also decreases from 7 months in the single-product model to 6 months in the two-product model. Interestingly, as shown in Figure 7, the implied kurtosis of price changes is higher in the two-product model than in the single-product model. This suggests that in this model with both rational inattention and menu costs, the ratio of kurtosis to the frequency of price changes might not be the sufficient statistic for the output response to a monetary shock, which is derived by Alvarez et al. (2016).[45]

How do the real effects change when I shut down each friction at a time? Consider the economy without informational costs, which is coincides to the standard menu cost models (e.g. Golosov and Lucas (2007); Midrigan (2011); Alvarez and Lippi (2014)). Figure A.5 shows the output responses in the pure menu cost models with the single- and two-product firms. The real effects of monetary policy shocks are larger in the two-product menu cost model than in the single-product menu cost model. Since economies of scope of menu cost technology generate many small price changes in the two-product model, selection effects of price changes are small in the two-product model and thus the real effects are larger than in the single-product model.

Next, I assume that firms are rationally inattentive, but free to adjust their prices without costs. This model coincides to the pure rational inattention models (e.g. Maćkowiak and Wiederholt (2009); Pasten and Schoenle (2016)). Figure A.6 shows that the output responses in the pure rational inattention models with the single- and two-product firms. The output effects are larger in the single-product model than in the two-product model since the two-product firms have more incentives to process information about aggregate shocks than the single-product firms. Since the

[45] The reason the rational inttention models are outside the class of models studied by Alvarez et al. (2016) is imperfect information about the monetary policy shocks. In their model, the real effects are calculated by the output responses to a once and for all unexpected monetary shock, which is perfectly observed by firms. Also, after the monetary shock, firms use the same decision rule used in the steady state. In the rational inattention model, however, firms do not have perfect information about the monetary policy shock, and their optimal policy rule depends on their uncertainty about the monetary shocks. More importantly, firms' optimal information acquisition is affected by their product scope. As I show in the following subsection, this makes the two-product firms be more informed about the monetary shocks than the single-product firms. Thus, monetary non-neutrality in the two-product model is smaller than that in the single-product model even if kurtosis of price changes is higher in the two-product model. This imperfect information about the monetary shocks breaks the application of the sufficient statistics derived by Alvarez et al. (2016) in this model.

single-product firms pay small attention to the monetary shocks, the aggregate prices respond sluggishly to the monetary shocks, leading to the larger real effects.

4.5 Inspecting Mechanisms

In this subsection, I investigate the key mechanisms behind the result of monetary non-neutrality in the baseline model. To this end, I start from the standard menu cost model with single-product firms such as Golosov and Lucas (2007), and consider counterfactual models by adding core elements of the baseline model. I discuss five main mechanisms; three of them have been studied in the previous literature while two of them are new in this paper. Figure 10 shows how each counterfactual model is related to the underlying mechanisms which I discuss here in detail.

Endogenous Leptokurtic Distribution. The first model (1A) is the standard menu cost model with single-product firms such as Golosov and Lucas (2007). In this model, firms have perfect information about both idiosyncratic and monetary shocks. As I discussed above, this model implies small and short-lived real effects of monetary shocks due to large selection effects of price changes (see the black solide line in Figure 11). For comparison with other counterfactual models, I normalize the impact response of output and the cumulative output responses in this model as 1.

In the next model (1B), I assume that the single-product firms have still perfect information about the monetary shock, but are rationally inattentive to their idiosyncratic good-specific shock. Since the firms choose their optimal signals about idiosyncratic shocks, selection in information processing about the idiosyncratic shock, which I discussed in the previous section, makes endogenously the distribution of firms' desired prices be leptokurtic. This implies that there are relatively small fraction of firms are around the inaction bands, leading to a small selection effects of price changes. Thus the real effects of monetary policy shocks in this model are larger than those in the only menu cost model with single-product firms. As shown in Figure 11, the impact output effect in the model (1B) increases by 31% compared to that in the only menu cost model with single product firms.[46] This mechanism is new in the literature; the interaction between menu costs and rational inattention generates the endogenous leptokurtic distribution of desired price changes, which amplifies the real effects of monetary shocks in a non-trivial way.

[46]Since firms have perfect information about the monetary shocks, and the aggregate demand follows a random walk process, they immediately observe and respond to the shocks if their prices are around the adjustment margins. It makes the real effects of monetary shocks in this counterfactual model also be short-lived.

Imperfect Information about Monetary Shocks. Next, I assume that the single-product firms are not only rationally inattentive to the good-specific shock and choose their optimal signals about it, but informationally constrained about the monetary policy shocks. I assume that all firms are *exogenously* given a signal about the monetary shocks, where the signal precision is the same with the steady-state average precision of signals in the baseline single-product model. In other words, if I choose a firm from this counterfactual economy, its attentiveness to the monetary shocks are the same with an average firm's attentiveness in the baseline single-product model. This counterfactual model (1C) captures the role of imperfect information about monetary policy shocks for monetary non-neutrality, which has been widely studied in the literature (e.g. Lucas (1972); Woodford (2003); Maćkowiak and Wiederholt (2009)). Figure 11 shows that this channel has the most important role for amplifying the real effects of monetary policy shocks. The cumulative output effects are seven times bigger in this model than those in the standard menu cost model. The large role of imperfect information stems from the calibration of the informational cost parameter since the New Zealand survey data show a large degree of informational rigidities for firm sides.

Selection in Information Processing about Monetary Shocks. Now, I assume that the single-product firms choose their optimal signal about the monetary policy shocks rather than receive an exogenous signal. This model (1D) is the baseline model with single-product firms that I studied in the previous section. The comparison of this model to the model (1C) captures the role of selection in information processing about the monetary shocks. Notice that while firms in both models (1C) and (1D) *on average* process the same amounts of information about the monetary shocks, selection in information processing leads price adjusters to have better information in the baseline model (1D). This implies that the firms who change their prices following the monetary shocks in the baseline model will adjust more strongly and learn quickly about the shocks compared to the price adjusting firms in the model (1C). Thus, the real effects of monetary shocks are smaller in this baseline model that those in the model (1C) with exogenous information about the monetary shock. Figure 11 confirms this result by showing that the cumulative output responses in the baseline model are 20 % smaller than those in the model (1C). This mechanism is also new in the literature.

Economies of Scope in Price Setting and Information Processing. Lastly, I consider the baseline model with two-product firms. The two-product model entails the economies of scope motives in both price setting and information processing that I discussed in the previous section. Notice that both economies of scope motives work in opposite directions for monetary non-neutrality. On the one hand, as shown by Alvarez and Lippi (2014) and Midrigan (2011), the economies of scope in price setting weaken selection effects of price changes by generating many small price changes, which act as a strong force to amplify the real effects of monetary shocks. On the other hand, Pasten and Schoenle (2016) show that the economies of scope in information processing implies that multi-product firms have better information about the monetary shocks than single-product firms, which makes monetary non-neutrality decrease in the number of products firms produce. Due to these opposite forces, it is not clear a priori the implications of multi-product pricing for monetary non-neutrality in the model with both rational inattention and menu costs. Figure 11 shows that the cumulative output effects of monetary shocks decrease by 20% in the two-product model than in the single-product model. This implies that the economies of scope in information processing are stronger than those in price setting in the calibrated model.

5 Extension

In this section, I study some extensions of the baseline model to study the robustness of the results about monetary non-neutrality.

5.1 Models with a Large Number of Products

In the previous section, I show that the real effects of monetary policy shocks decrease in the baseline two-product model compared to the single-product model. In this section, I analyze whether this implication of multi-product pricing for monetary non-neutrality can be extended to the models with arbitrary many number of products. The main computational challenge for solving the model with more than two products is that the number of state variables increases linearly in the number of products. To simplify the analysis, I make two assumptions. First, I assume that firms choose how much process information about the underlying shocks *as if* they do not have menu costs. Second, given menu costs, firms choose their prices based on that information, but they are *myopic* in a sense that they do not care about the continuation value of their current pricing decisions. One disadvantage of taking these assumptions is that it eliminates the interesting interaction between rational inattention and menu costs; under these assumptions, all firms have the same information set about the underlying shocks. However, since it simplifies the model analysis by eliminating the state variables, but keeps the core of the baseline model, I analyze the implications of the multi-product pricing for monetary non-neutrality under these assumptions.[47]

Figure 12 shows that the cumulative responses of output to a monetary policy shock in the simplified models with various number of products. I calibrate the size and frequency of price changes to be the same across all models with different number of products. I normalize the cumulative output response in the only menu cost model with single-product firms as one. In the only menu cost models (red line), the cumulative output effects are increasing in firms' number of products, which is consistent with the finding in Alvarez and Lippi (2014). In the models with both rational inattention and menu costs (blue line), the real effects decrease in the number of products, but converge to the only menu cost models with large number of products. As the number of products increases in the model, firms' subjective uncertainty about monetary policy shocks decreases and converges to zero, implying firms have almost perfect information about the monetary shocks.[48] Again, this implies that the ratio of kurtosis to the frequency of price changes might not be the sufficient statistic for monetary non-neutrality in the models with both rational inattention and menu costs. I also consider the model that exactly matches the distribution of number of products across firms in New Zealand. The black dashed line shows that the cumulative output effect of that model is larger than that in the single-product menu cost model, but smaller than that in the Calvo sticky price model.[49] This implies that my main conclusion about the relationship between monetary non-neutrality and firms' product scope can be extended to the model with a large number of products.

6 Conclusion

Understanding the nature of firms' expectations formation and price setting behavior has been primary interests in monetary economics. In this paper, I focus on multi-product firms' incentives of processing information and changing prices. I find two stylized facts that show how firms' product scope is related to their expectations formation and price setting behavior: firms with a greater number of products have both 1) better information about aggregate inflation, and 2)

[47] For example, as shown in Figure A.7 in Appendix, the backcast errors about the growth rate of nominal GDP decreases in the number of products. This stems from the economies of scope in information processing in the rational inattention model with multi-product firms. Moreover, kurtosis of the distribution of price changes increases in the number of products and converges to the value of three, which is consistent with the implications of menu cost models with multi-product firms.

[48] In fact, equation (6) clearly shows this negative relationship between the number of products and firms' subjective uncertainty about monetary policy shocks.

[49] The median number of products in the New Zealand survey data is 7 excluding retail and wholesale trade firms. Interestingly, the cumulative output responses in this model are similar to the model with firms that produce the median number of products.

more frequent but smaller price changes. I develop a dynamic general equilibrium menu cost model with rationally inattentive multi-product firms, which is disciplined by the empirical facts, to study the aggregate implications for monetary non-neutrality. In this model, the interaction between nominal and informational rigidities give rises to a novel selection effect in information processing, which lead to an endogenize leptokurtic distribution of desired price changes. I show that the endogenous leptokurtic distribution weakens selection effects of price changes. As a result, the real effects of monetary policy shocks in the one-good version of the model are nearly as large as those in the Calvo model. Finally, I show that in the two-good version of the model, the cumulative output effects decrease by 20% than the one-good version of the model due to the strong economies of scope motive in information processing.

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Tables and Figures

Table 1: Number of Products and Knowledge about Aggregate Inflation

	(1)	(2)	(3)	(4)
Panel A. Dependent variable: Inflation backcast errors				
log(# of products)	-0.326**	-0.214***	-0.588***	-0.251***
	(0.145)	(0.060)	(0.149)	(0.060)
Observations	591	580	446	439
R-squared	0.339	0.800	0.345	0.899
Panel B. Dependent variable: Willingness to pay for professional inflation forecasts				
log(# of products)	7.664***	3.503***	7.207**	3.850**
	(2.931)	(1.210)	(2.949)	(1.661)
Observations	381	367	326	317
R-squared	0.202	0.657	0.273	0.705
Firm-level controls	Yes	Yes	Yes	Yes
Industry FE		Yes		Yes
Manager controls			Yes	Yes

Notes: This table reports results for the Huber robust regression. Dependent variables are the absolute value of firm errors about past 12 month inflation from Wave #1 survey (Panel A) and firms' willingness to payment for professional forecaster's forecasts about future inflation from Wave #4 (Panel B). Firm-level controls include log of firms' age, log of firms' employment, foreign trade share, number of competitors, firms' beliefs about price difference from competitors, and the slope of the profit function. Industry fixed effects include dummies for 14 sub-industries excluding retail and wholesale trade sectors. Manager controls include the age of the respondent (each firm's manger), education, income, and tenure at the firm. Sample weights are applied to all specifications. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively. See section 2.1 for details.

Table 2: Number of Products and Information Updates

	(1)	(2)	(3)	(4)	(5)
Dependent variable: Posterior belief about aggregate inflation (p_i)					
Prior (μ_i)	0.357***	0.197***	0.203**	0.335**	0.542***
	(0.025)	(0.068)	(0.077)	(0.125)	(0.054)
$N_i^{\text{product}} \times \mu_i$		0.186**	0.068*	0.063*	0.475***
		(0.075)	(0.037)	(0.035)	(0.124)
N_i^{product}		-0.578*	-0.332**	-0.313**	-1.145*
		(0.315)	(0.130)	(0.136)	(0.641)
N_i^{product}		$\mathbf{1}_{\{N \geq 4\}}$	$\log(N)$	$\log(N)$	1-output share of main product
Firm size control				Yes	Yes
Observations	130	130	130	130	411
R-squared	0.367	0.410	0.401	0.395	0.512

Notes: This table reports Huber robust regressions of the posterior point prediction of the 12-month-ahead forecasts of inflation on the prior, i.e. the point prediction implied by the reported probability distribution for the future inflation. The prior is the belief of a firm before the firm is presented with additional information. The posterior is the belief of a firm after the firm is presented with additional information. Fixed effects for source of information are included but not reported. Column (2) includes a dummy variable which is 1 if firms' number of products is greater than or equal to 4, and its interaction with the prior. Column (3) and (4) include log of firms' number of products and its interaction with the prior. Column (5) includes 1-the share of total production value for main product and its interaction with the prior. In Column (4) and (5), I add log of firms' employment and its interaction with the prior as controls. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively. See section 2.1.1 for details.

Table 3: The Treatment Effects of Information about RBNZ Inflation Target on Firms' Choice

	No controls for firm characteristics		Controls for firm characteristics	
	$N \leq 4$	$N > 4$	$N \leq 4$	$N > 4$
	(1)	(2)	(3)	(4)
Change in expectations immediately after treatment				
One-year ahead inflation	-0.612**	0.345	-0.672*	0.281
	(0.275)	(0.367)	(0.373)	(0.251)
Forecast error in firm-level outcome				
Wage growth	0.227	-0.058	0.053	-0.120
	(0.204)	(0.059)	(0.228)	(0.078)
Investment growth	-3.196**	-0.252	-4.969*	-0.932
	(1.597)	(0.882)	(2.782)	(0.991)
Employment growth	-2.467*	0.394	0.148	-0.415
	(1.411)	(1.395)	(2.187)	(1.572)
Price change	-1.267***	-0.206	-1.299***	-0.123
	(0.258)	(0.131)	(0.228)	(0.190)

Notes: The table shows estimates of the treatment effect of providing information about the inflation target of the Reserve Bank of New Zealand on firms with a smaller number of products (columns (1) and (3)) and on firms with a greater number of products (column (2) and (4)). N stands for the number of products that firms produce. Firm characteristics, such as log of firms' age, log of firms' employment, number of competitors, and the slope of the profit function, are included in column (3) and (4). Influential observations are identified as observations that move the estimation by more than 0.5 of the standard error. These observations are excluded. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively. See section 2.1.2 for details.

Table 4: Number of Products and Duration and Size of Price Changes

	(1)	(2)	(3)	(4)
Panel A. Dependent variable: Duration of expected next price changes				
log(# of products)	-0.266*	-0.253**	-0.435***	-0.597***
	(0.159)	(0.121)	(0.156)	(0.143)
Observations	587	578	445	442
R-squared	0.419	0.557	0.445	0.511
Panel B. Dependent variable: Size of expected next price changes				
log(# of products)	-0.048	-0.260***	-0.058	-0.281***
	(0.094)	(0.070)	(0.099)	(0.088)
Observations	576	575	431	426
R-squared	0.021	0.599	0.055	0.499
Firm-level controls	Yes	Yes	Yes	Yes
Industry FE		Yes		Yes
Manager controls			Yes	Yes

Notes: This table reports results for the Huber robust regression. Dependent variables are the duration of expected next price changes from Wave #1 (Panel A) and the (absolute) size of expected next price changes from Wave #1 survey (Panel B). Firm-level controls include log of firms' age, log of firms' employment, foreign trade share, number of competitors, and firms' beliefs about price difference from competitors. Industry fixed effects include dummies for 14 sub-industries excluding retail and wholesale trade sectors. Manager controls include the age of the respondent (each firm's manger), education, income, and tenure at the firm. Sample weights are applied to all specifications. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively. See section 2.2 for details.

Table 5: Data and Model Moments

	Data	Single-product model	Two-product model
Median (absolute) size of price changes	0.0656	0.0656	0.0656
Median frequency of price changes	0.0833	0.0833	0.0833
Slope of the backcast error curve	-0.026	-0.027	

Notes: The table presents moments of the data and simulated series from the single- and two-product models parameterized at the baseline values in Table 6. To get the slope of the backcast error curve, I regress the absolute value of firm errors about past 12 month nominal GDP growth rate from Wave #4 survey on the number of products each firm produces. Regression results are reported in Table A.5 in appendix. See section 4.2 for details.

Table 6: Calibration and Assigned Parameters

	Single-product model	Two-product model
Panel A. Calibrated parameters		
Menu cost (θ)	0.0093	0.0342
Information cost (ψ)	0.0070	0.0070
S.D. of idiosyncratic shocks (σ_a)	0.0189	0.0212
S.D. of monetary policy shocks (σ_m)	0.0065	0.0065
Panel B. Assigned parameters		
Time discount factor (β)	0.9966	0.9966
Elasticity of substitution across firms (ε)	4.0	4.0
Elasticity of substitution between goods (γ)		4.0

Notes: The table presents the baseline parameters for the general equilibrium models with single- and two-product firms. Panel A shows the calibrated parameters which match the three key moments shown in Table 5. Panel B shows the assigned parameters. See section 4.2 for details.

Table 7: Average Kalman Gains in Models

	Single-product model		Two-product model	
	(1) Kalman gain about $a_{i,j,t}$ ($\mathcal{K}^a$)	(2) Kalman gain about m_t ($\mathcal{K}^m$)	(3) Kalman gain about $a_{i,j,t}$ ($\mathcal{K}^a$)	(4) Kalman gain about m_t ($\mathcal{K}^m$)
Total	0.219	0.094	0.231	0.124
- Price adjusters	0.556	0.276	0.618	0.411
- Price non-adjusters	0.188	0.078	0.196	0.098

Notes: The table presents average Kalman gains across firms in the baseline single- and two-product models. Column (1) and (3) show the average Kalman gains on the signal about the idiosyncratic good-specific shocks in the single-product model and those in the two-product model, respectively. Column (2) and (4) show the average Kalman gains on the signal about the monetary policy shock in the single-product model and those in the two-product model, respectively.

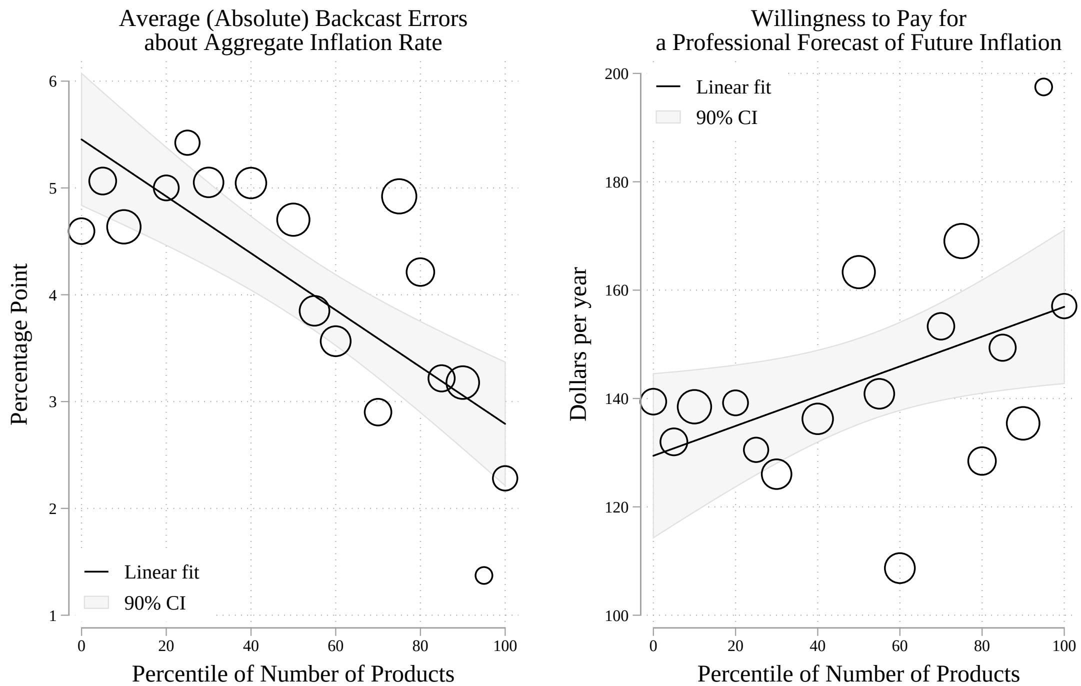


Figure 1: Number of Products and Attentiveness to Aggregate Inflation

Notes: The left panel plots percentile of firms' number of products versus the average of firm backcast errors about past 12 month inflation within each percentile. The right panel plots the percentile of firms' number of products versus the average of willingness to pay for a professional forecast of future inflation. The willingness to pay is measured from answers to the following question in Wave #4 survey: *"How much would you pay per year to have access to a monthly magazine of professional forecasts of future inflation?"* Black lines are linear fitted lines and shaded areas are 90% confidence intervals. The size of bins represents average size of employment of firms in each percentile.

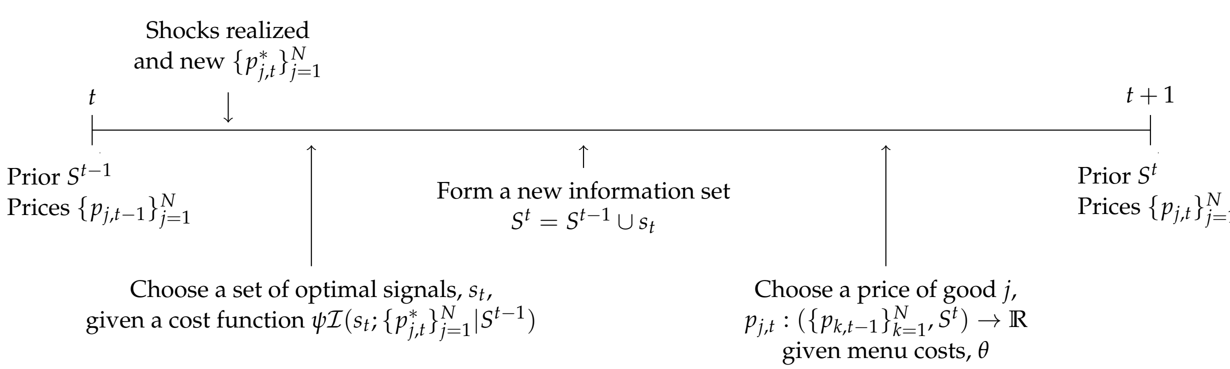


Figure 2: Timing of Events for a Firm's Problem

Notes: This figure shows a sequence of events in each period of the model. See section 3.1 for details.

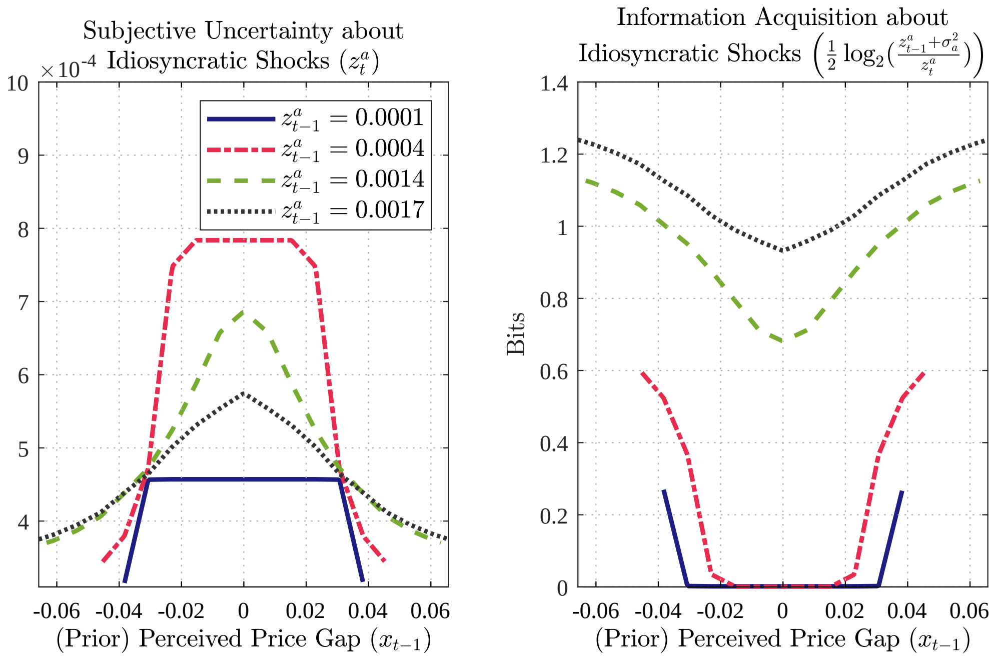


Figure 3: Subjective Uncertainty and Information Acquisition about an Idiosyncratic Shock

Notes: The left panel plots a single-product firm's optimal decision rule for subjective uncertainty about a good-specific shock, $z_t^a(x_{t-1}, z_{t-1}^a, z_{t-1}^m)$, when $z_{t-1}^m = 0.00016$. The right panel plots the implied amounts of information acquisition from the optimal choice of subjective uncertainty about the good-specific shock.

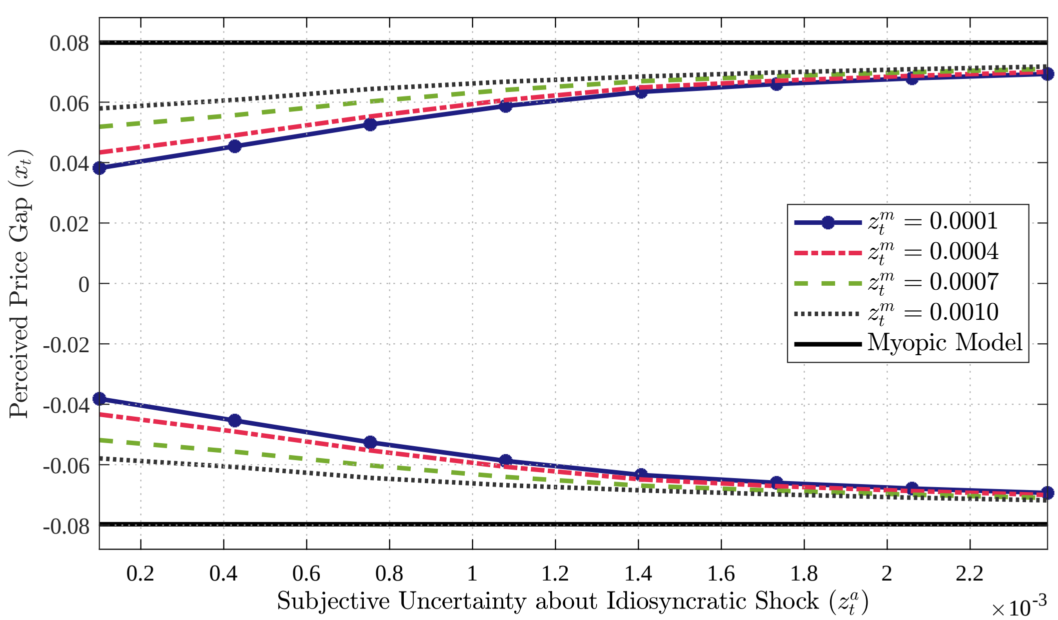


Figure 4: Inaction Bands of a Single-Product Firm by Subjective Uncertainty

Notes: This figure shows inaction bands of a single-product firm as a function of its subjective uncertainty. Different lines represent the inaction bands with different levels of subjective uncertainty about the aggregate shock (z_t^m). Black lines are the inaction bands of a myopic firm whose discount factor is zero. Since this myopic firm does not care about a continuation value of information, the subjective uncertainty is not its state variable, which leads the inaction bands of this firm to be constant.

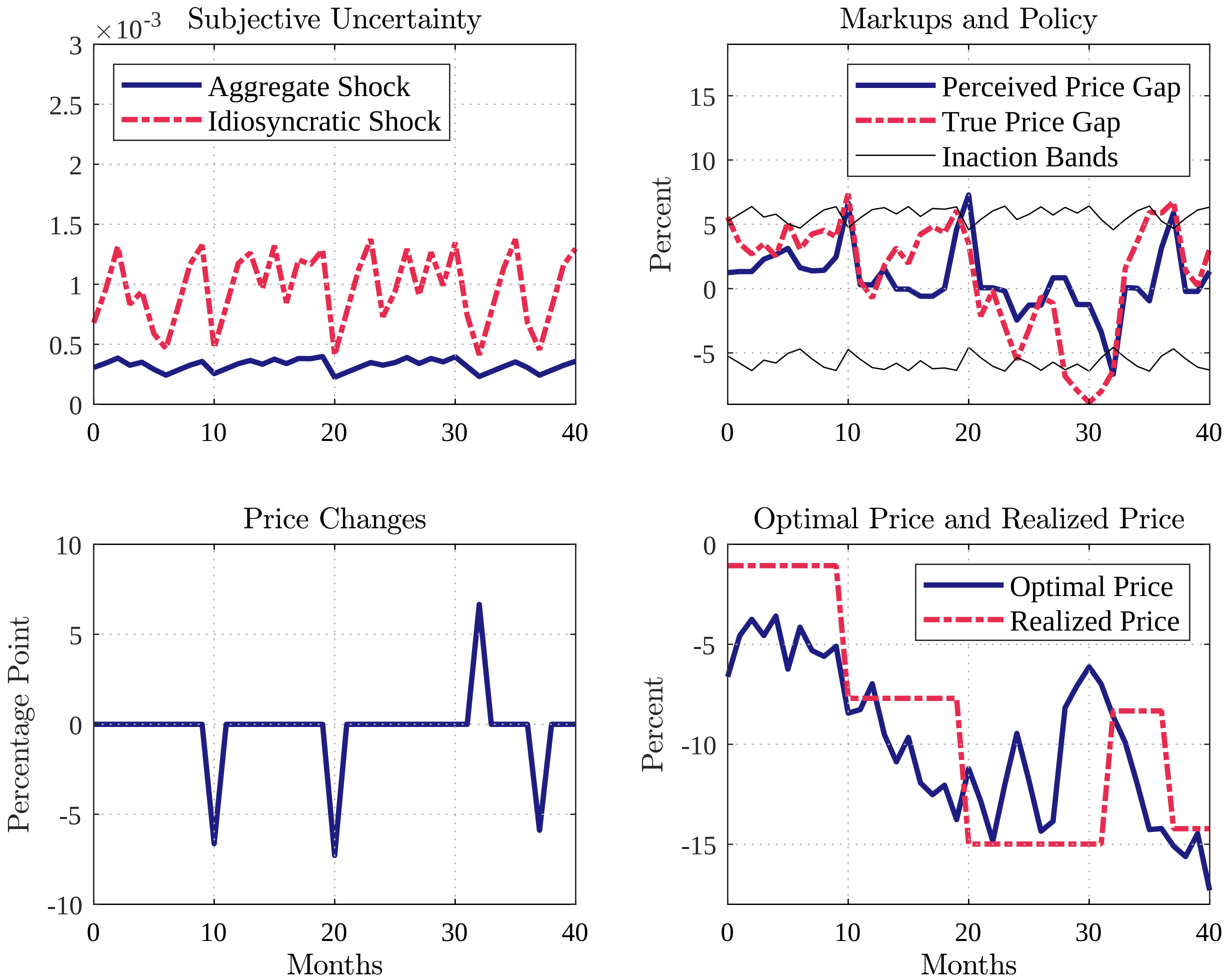


Figure 5: A Single-Product Firm Simulation

Notes: The upper left panel plots a single-product firm's subjective uncertainty about both a good-specific shock (red dash-dot line) and an aggregate shock (blue solid line). The upper right panel plots the firm's perceived price gap (x_t), its true price gap under perfect information, and inaction bands. The firm changes its price when the perceived price gap is out of the inaction bands. The lower left panel plots these price changes. The lower right panel plots realized actual prices and optimal prices under perfect information.

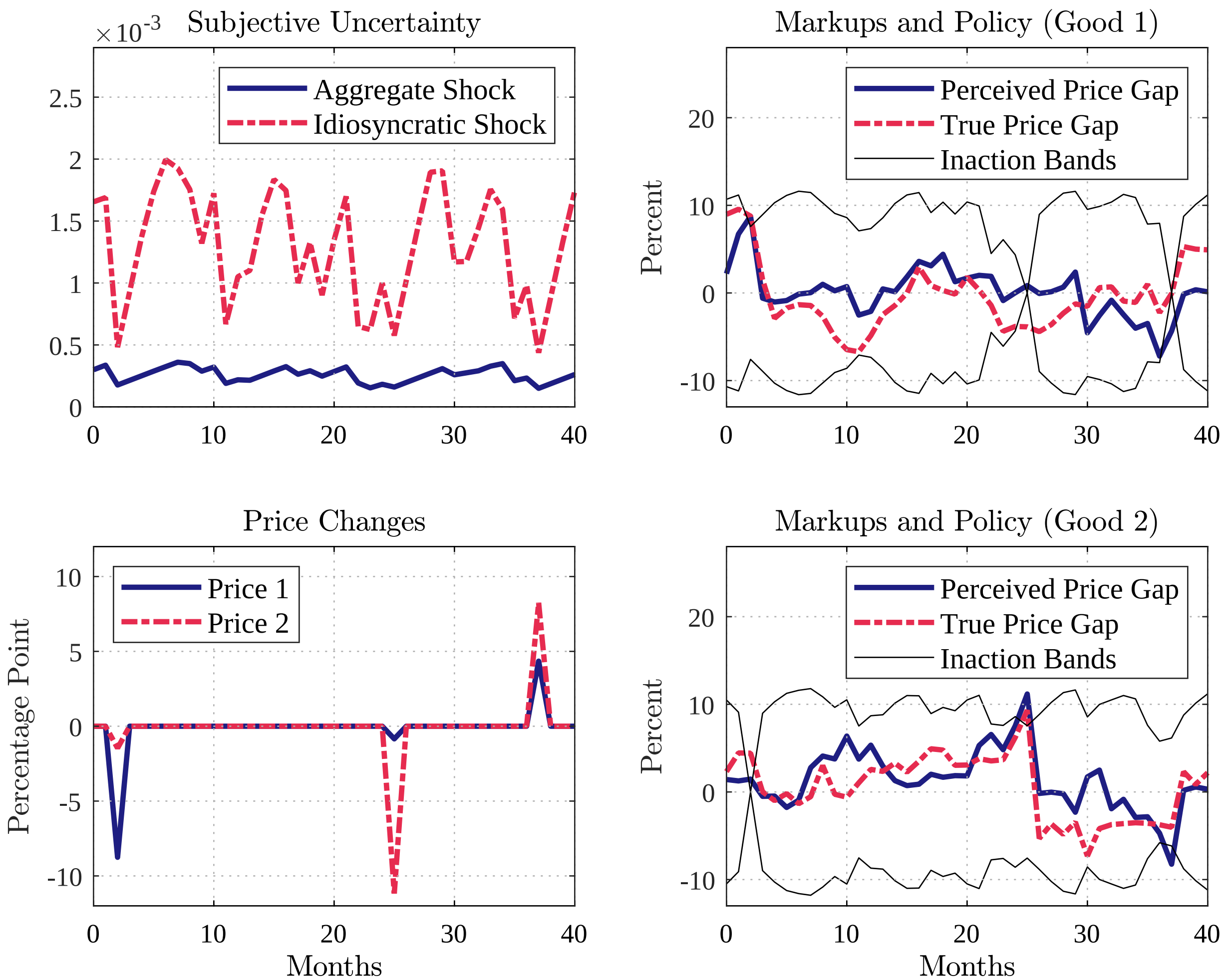


Figure 6: A Two-Product Firm Simulation

Notes: The upper left panel plots a two-product firm's subjective uncertainty about both a good-specific shock (red dash-dot line) and an aggregate shock (blue solid line). The upper right panel plots the firm's perceived price gap (x_t) for good 1, its true price gap for good 1 under perfect information, and inaction bands for good 1. The lower right panel plots the firm's perceived price gap (x_t) for good 2, its true price gap for good 2 under perfect information, and inaction bands for good 2. The firm changes its price when the perceived price gaps are out of the inaction bands. The lower left panel plots these price changes for both goods.

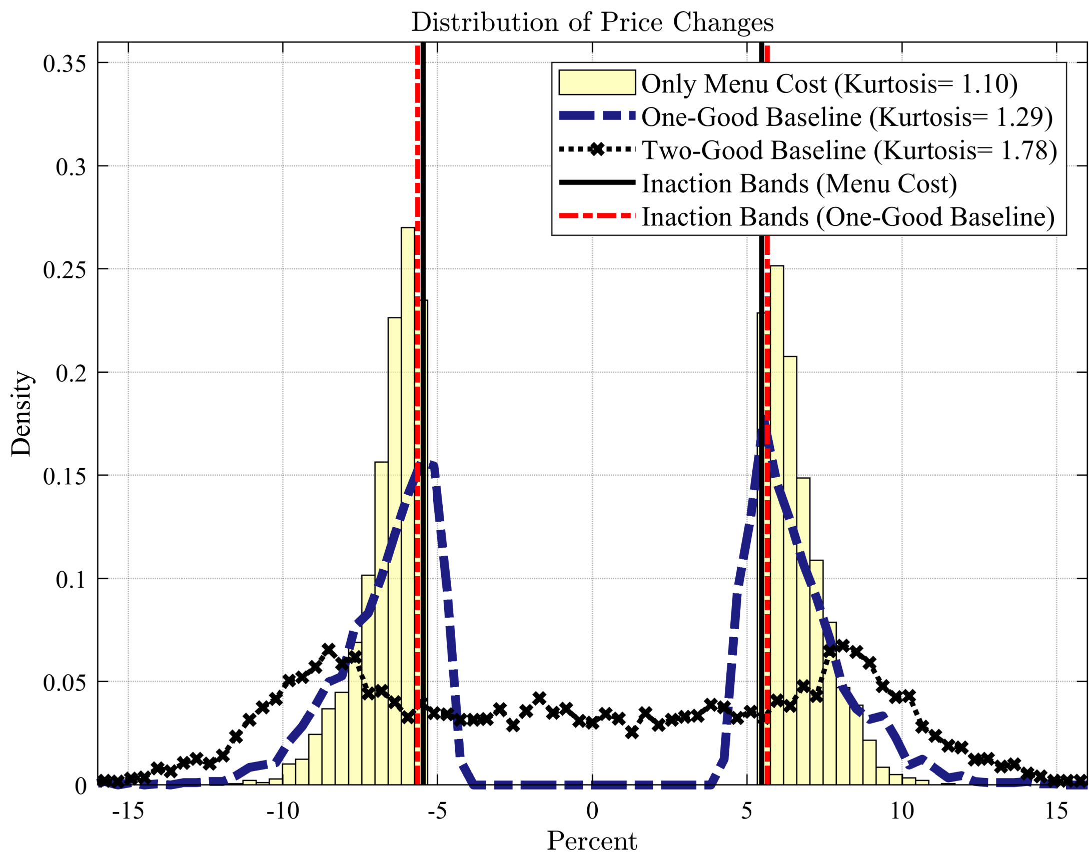


Figure 7: Distributions of Price Changes

Notes: This figure plots the distribution of price changes in the single-product only menu cost model (yellow bar), that in the baseline single-product model (blue dashed line), and that in the baseline two-product model (black line with cross markers). Black vertical lines are the inaction bands for firms in the only menu cost model. In this model, every firms have the same inaction bands. Red vertical dash-dot lines are the average of inaction bands across firms in the baseline single-product model. Notice that in this model, the inaction bands vary with firms' subjective uncertainty, as shown in Figure 4.

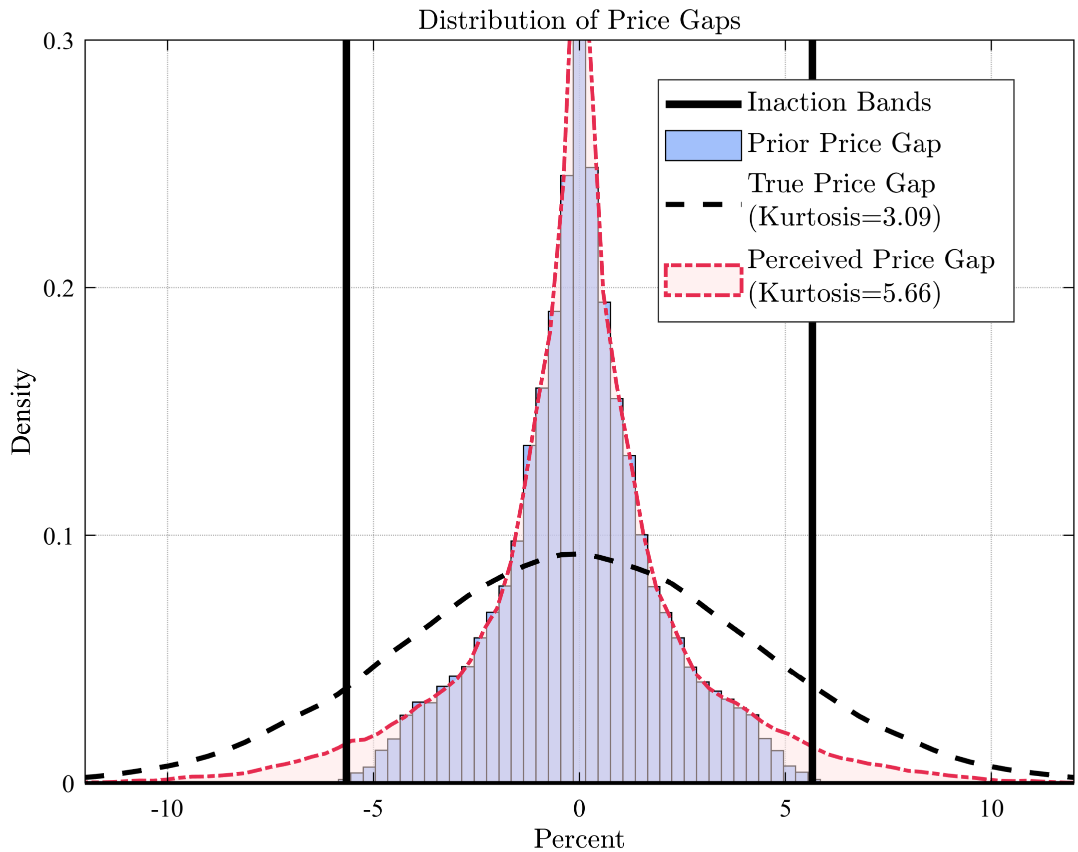


Figure 8: Distributions of True and Perceived Price Gaps in the Single-Product Model

Notes: This figure plots distributions of price gaps in the single-product baseline model. Black lines are the average of inaction bands across firms in the model. At the beginning of period, before the realization of shocks, all firms believe that their price is within the inaction bands. Blue bar graph shows the distribution of firms' *prior* about their price gaps ($p_{i,j,t-1} - \mathbb{E}_{t-1}[p^*_{i,j,t}|S^{t-1}]$) at the beginning of period. After the Gaussian shocks realized, firms' marginal costs change, and thus their true price gap ($p_{i,j,t-1} - p^*_{i,j,t}$) also changes. Black dashed line shows the distribution of these true price gaps. Firms choose their optimal signals about the shocks and form a new posterior about their (frictionless) optimal price. Then, the *posterior* of perceived price gap is $p_{i,j,t-1} - \mathbb{E}_t[p^*_{i,j,t}|S^t]$. Red dash-dot line shows the distribution of these perceived price gaps.

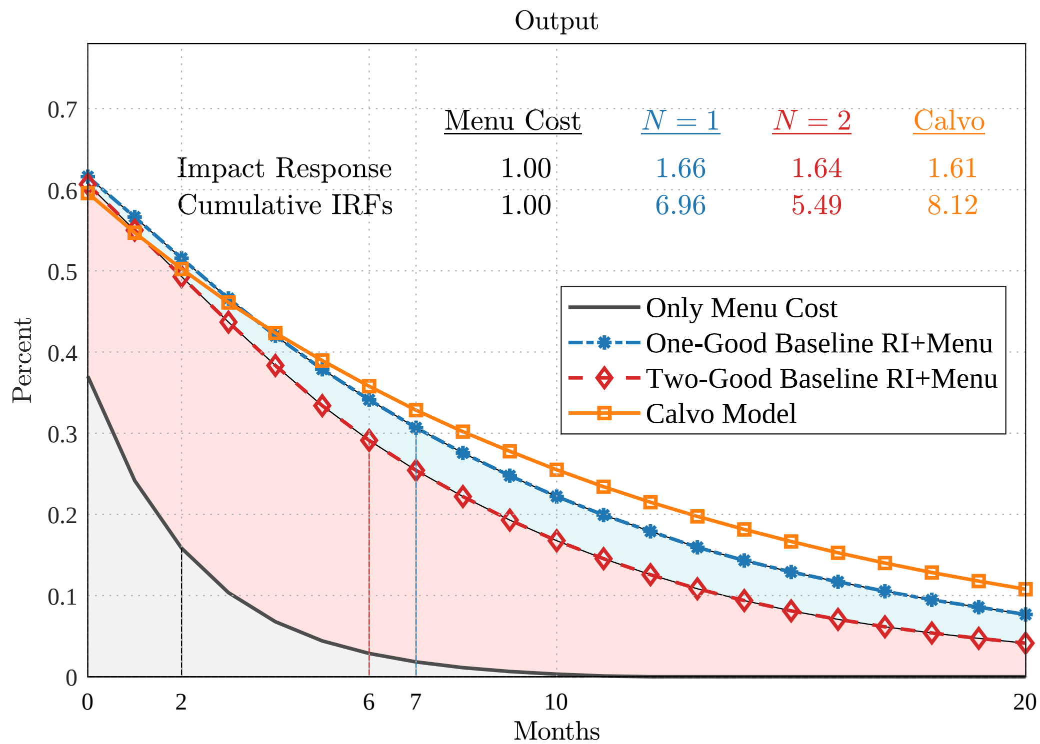


Figure 9: Impulse Response of Output to a One S.D. Monetary Shock

Notes: This figure plots impulse responses of output to a one standard deviation monetary shock. Cumulative IRFs refers to area under the responses of output. I normalize both impact response and cumulative output response in the only menu cost model with single-product firms as 1.

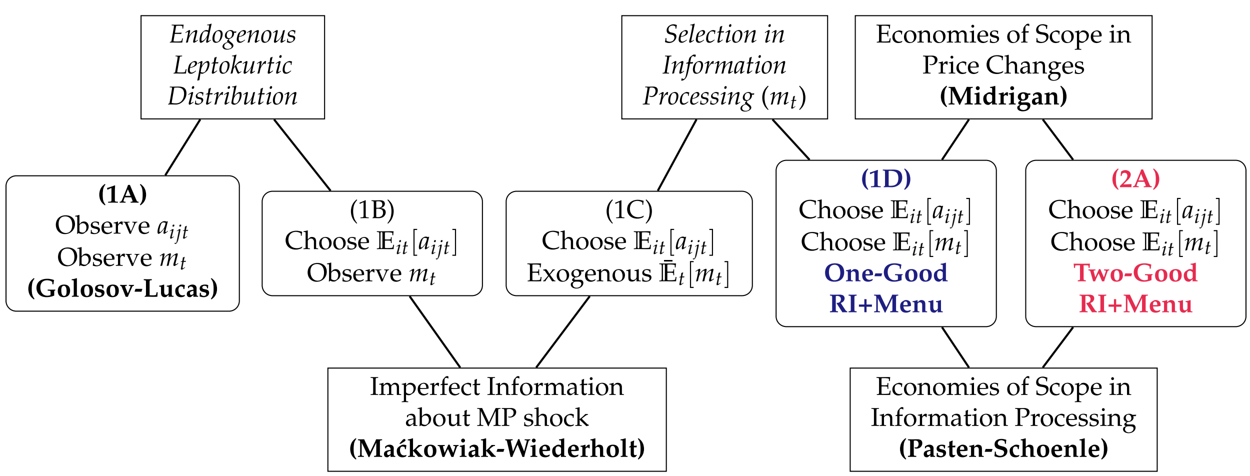
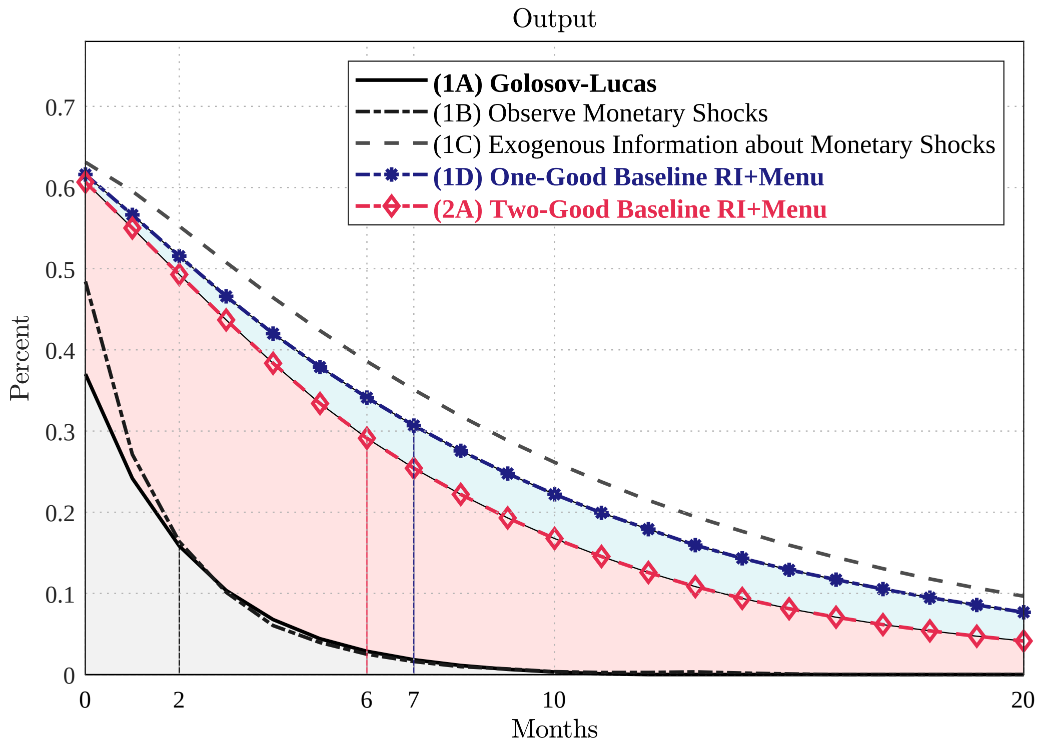


Figure 10: Counterfactuals and Model Mechanism

Notes: This figure shows counterfactual models and the implied model mechanisms. Model (1A), (1B), (1C), and (1D) are single-product menu cost models with different assumptions about firms' information set. In model (1A), firms have full-information about both idiosyncratic and monetary shocks. Firms in model (1B) have perfect information about the monetary shock, but choose their optimal signal about the idiosyncratic shock. All firms in model (1C) are given the same exogenous signal about the monetary shock, while they choose their optimal signals about the idiosyncratic shock. Model (1D) is the baseline single-product model where all firms choose their optimal signals about both shocks. Model (2D) is the baseline two-product model. See section 4.5 for details.



	(1A)	(1B)	(1C)	**(1D)**	**(2A)**
Impact Response	**1**	1.31	1.70	**1.66**	**1.64**
Cumulative IRFs	**1**	1.08	8.18	**6.96**	**5.49**

Figure 11: Impulse Responses of Output in Counterfactual Models

Notes: This figure plots impulse responses of output to a one standard deviation monetary shock in counterfactual models described in Figure 10. Cumulative IRFs refers to area under the responses of output. I normalize both impact response and cumulative output response in the only menu cost model with single-product firms as 1. See section 4.5 for details.

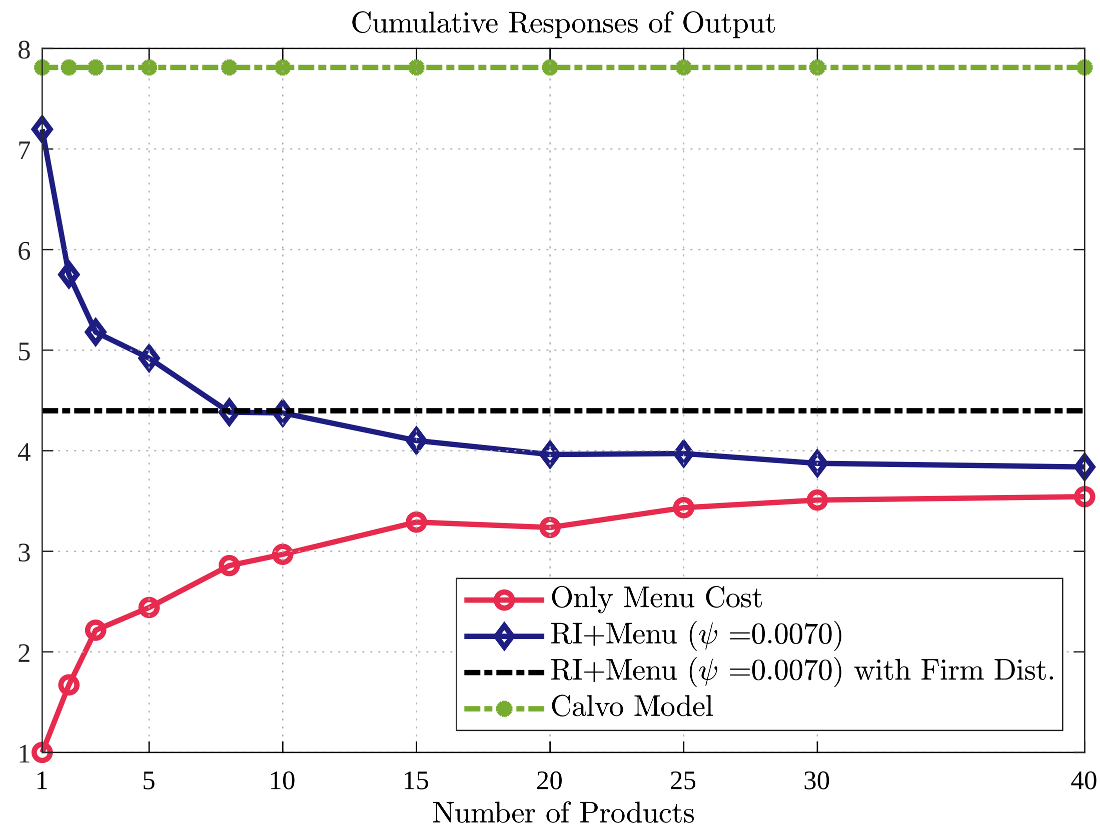


Figure 12: Cumulative Output Responses and Number of Products in the Simplified Models

Notes: This figure plots cumulative output responses in the simplified models with different number of products. RI+Menu refers to the model with both menu costs and rational inattention. Red line shows the cumulative output responses in the only menu cost models with different number of products and blue line shows those in the models with both menu costs and rational inattention with different number of products. Black line shows the cumulative response of output in the RI+Menu model with the same firm distribution of number of products observed in the New Zealand data. See section 5.1 for details.

APPENDIX FOR ONLINE PUBLICATION

A Quadratic Approximation of a Firm's Profit Function

Firm i produces N products indexed by j in monopolistic competitive markets. Its demand for good j is given by

$$Y_{i,j,t} = \left(\frac{P_{i,j,t}}{P_{j,t}}\right)^{-\varepsilon} \left(\frac{P_{j,t}}{P_t}\right)^{-\gamma} Y_t$$

where P_t is the price of aggregate output Y_t, $P_{j,t}$ is the price of good j, γ is the constant elasticity of substitution across different firms that produce the same good, and ε is the constant elasticity of substitution across different goods. Then, the firm's profit function is

$$\begin{aligned}\Pi_{i,t} &= \sum_{j=1}^{N} \left(P_{i,j,t} - W_t A_{i,j,t}\right) Y_{i,j,t} \\ &= \sum_{j=1}^{N} \left(P_{i,j,t} - W_t A_{i,j,t}\right) \left(\frac{P_{i,j,t}}{P_{j,t}}\right)^{-\varepsilon} \left(\frac{P_{j,t}}{P_t}\right)^{-\gamma} Y_t,\end{aligned}$$

where

$$P_t = \left(\frac{1}{N}\sum_{j=1}^{N} P_{j,t}^{1-\gamma}\right)^{\frac{1}{1-\gamma}}, \quad P_{j,t} = \left(\int_0^1 \left(P_{i,j,t}\right)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}$$

Define firm i's markup for good j, $\mu_{i,j,t} = \frac{P_{i,j,t}}{W_t A_{i,j,t}}$. Then, the profit function can be written as a function of the firm's markups for each good:

$$\begin{aligned}\Pi_{i,t} &= \sum_{j=1}^{N} \left(P_{i,j,t} - W_t A_{i,j,t}\right) \left(\frac{P_{i,j,t}}{P_{j,t}}\right)^{-\varepsilon} \left(\frac{P_{j,t}}{P_t}\right)^{-\gamma} Y_t \\ &= \sum_{j=1}^{N} \left(\mu_{i,j,t} - 1\right) \left(\mu_{i,j,t}\right)^{-\varepsilon} \left(W_t A_{i,j,t}\right)^{1-\varepsilon} \left(P_{j,t}\right)^{\varepsilon-\gamma} \left(P_t\right)^{\gamma} Y_t.\end{aligned}$$

Let $R_{i,j,t}$ be the revenue from good j:

$$\begin{aligned}R_{i,j,t} &= P_{i,j,t} \left(\frac{P_{i,j,t}}{P_{j,t}}\right)^{-\varepsilon} \left(\frac{P_{j,t}}{P_t}\right)^{-\gamma} Y_t \\ &= \mu_{i,j,t} \left(\mu_{i,j,t}\right)^{-\varepsilon} \left(W_t A_{i,j,t}\right)^{1-\varepsilon} \left(P_{j,t}\right)^{\varepsilon-\gamma} \left(P_t\right)^{\gamma} Y_t.\end{aligned}$$

A second order approximation to the profit function around the optimal frictionless markup, $\mu_j^* = \frac{\varepsilon}{\varepsilon-1}$, yields

$$
\begin{aligned}
\Pi\left(\left\{\mu_{j,t}\right\}_{j=1}^{N}\right) &= \Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right) + \frac{1}{2}\sum_{j=1}^{N} \left.\frac{\partial^2 \Pi_t}{\partial \mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^{N}} \left(\frac{\mu_{j,t}-\mu_j^*}{\mu_j^*}\right)^2 \left(\mu_j^*\right)^2 \\
&= \Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right) + \frac{1}{2}\sum_{j=1}^{N} \left.\frac{\partial^2 \Pi_t}{\partial \mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^{N}} \left(\hat{\mu}_{j,t}\right)^2 \left(\mu_j^*\right)^2
\end{aligned}
$$

where $\hat{\mu}_{j,t} = \log\left(\mu_{j,t}\right) - \log\left(\mu_j^*\right)$ is the realized markup-gap. Then, given the CES demand and the constant returns to scale technology, we can express the expected losses that arise from frictions (both nominal and informational) relative to the frictionless case, expressed as a fraction of per-good revenue:

$$
\begin{aligned}
\mathcal{L} &\equiv \mathbb{E}\left[\left.\frac{\Pi\left(\left\{\mu_{j,t}\right\}_{j=1}^{N}\right) - \Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right)}{R\left(\mu_j^*\right)}\right| S^{t-1}\right] \\
&= \frac{1}{2}\mathbb{E}\left[\left.\frac{1}{R\left(\mu_j^*\right)}\sum_{j=1}^{N} \left.\frac{\partial^2 \Pi_t}{\partial \mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^{N}} \left(\hat{\mu}_{j,t}\right)^2 \left(\mu_j^*\right)^2 \right| S^{t-1}\right] \\
&= \frac{1}{2}\mathbb{E}\left[\left.\frac{\Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right)}{R\left(\mu_j^*\right)}\sum_{j=1}^{N} \frac{\left(\mu_j^*\right)^2 \left.\frac{\partial^2 \Pi_t}{\partial \mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^{N}}}{\Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right)} \left(\hat{\mu}_{j,t}\right)^2 \right| S^{t-1}\right]
\end{aligned}
$$

where

$$
\begin{aligned}
\left.\frac{\partial^2 \Pi_t}{\partial \mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^{N}} &= \varepsilon\left(\mu_j^*\right)^{-\varepsilon-2}\left[(\varepsilon+1)\left(\mu_j^*-1\right) - 2\mu_j^*\right]\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y} \\
&= -\varepsilon\left(\mu_j^*\right)^{-\varepsilon-2}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}
\end{aligned}
$$

$$
\Pi\left(\left\{\mu_j^*\right\}_{j=1}^{N}\right) = \sum_{j=1}^{N}\left(\mu_j^*-1\right)\left(\mu_j^*\right)^{-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y},
$$

and

$$
R\left(\mu_j^*\right) = \left(\mu_j^*\right)^{1-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}.
$$

Then, the loss function is

$$
\begin{aligned}
\mathcal{L} &= \frac{1}{2}\mathbb{E}\left[\frac{\Pi\left(\left\{\mu_j^*\right\}_{j=1}^N\right)}{R\left(\mu_j^*\right)}\sum_{j=1}^N \frac{\left(\mu_j^*\right)^2 \left.\frac{\partial^2\Pi_t}{\partial\mu_{j,t}^2}\right|_{\left\{\mu_{j,t}=\mu_j^*\right\}_{j=1}^N}}{\Pi\left(\left\{\mu_j^*\right\}_{j=1}^N\right)}\left(\hat{\mu}_{j,t}\right)^2 \middle| S^{t-1}\right] \\
&= -\varepsilon\frac{1}{2}\mathbb{E}\Bigg[\left(\frac{\sum_{j=1}^N\left(\mu_j^*-1\right)\left(\mu_j^*\right)^{-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}}{\left(\mu_j^*\right)^{1-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}}\right) \\
&\qquad\qquad \times\frac{\sum_{j=1}^N\left(\mu_j^*\right)^{-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}}{\sum_{j=1}^N\left(\mu_j^*-1\right)\left(\mu_j^*\right)^{-\varepsilon}\left(\bar{W}\right)^{1-\varepsilon}\left(\bar{P}_j\right)^{\varepsilon-\gamma}\left(\bar{P}\right)^{\gamma}\bar{Y}}\left(\hat{\mu}_{j,t}\right)^2\middle| S^{t-1}\Bigg].
\end{aligned}
$$

Now, assume $\varepsilon = \gamma$ (or by symmetry across product industry due to there are no common industry specific shocks). Then, the second order approximation of the firm's profit function is

$$
\begin{aligned}
\mathcal{L} &= -\varepsilon\frac{1}{2}\mathbb{E}\left[\left(\frac{1}{\mu_j^*}\right)\sum_{j=1}^N\left(\hat{\mu}_{j,t}\right)^2\middle| S^{t-1}\right] \\
&= -\frac{\varepsilon-1}{2}\mathbb{E}\left[\sum_{j=1}^N\left(\hat{\mu}_{j,t}\right)^2\middle| S^{t-1}\right].
\end{aligned}
$$

B Simulation Algorithm for the Two-Good Model

I simulate the two-good economy with 100,000 firms for 5,000 periods. Each firm produces good A and B.

1. Set initial $x_{i,A,t-1}$, $x_{i,B,t-1}$, $z^a_{i,A,t-1}$, $z^a_{i,B,t-1}$, and $z^m_{i,t-1}$.
2. Generate random numbers for the shocks $\varepsilon^m_t \sim N(0,\sigma_m^2)$, $\varepsilon^a_{i,A,t} \sim N(0,\sigma_a^2)$, and $\varepsilon^a_{i,B,t} \sim N(0,\sigma_a^2)$
3. Find $z^m_{i,t}$, $z^a_{i,A,t}$, and $z^a_{i,B,t}$, given policy functions,

$$
\begin{aligned}
&g^A\left(x_{i,A,t-1}, x_{i,B,t-1}, z^a_{i,A,t-1}, z^a_{i,B,t-1}, z^m_{i,t-1}\right)\\
&g^B\left(x_{i,A,t-1}, x_{i,B,t-1}, z^a_{i,A,t-1}, z^a_{i,B,t-1}, z^m_{i,t-1}\right)\\
&g^m\left(x_{i,A,t-1}, x_{i,B,t-1}, z^a_{i,A,t-1}, z^a_{i,B,t-1}, z^m_{i,t-1}\right).
\end{aligned}
$$

4. Calculate standard deviations of signal noises and Kalman gains from

$$
\begin{aligned}
z^m_{i,t} &= \left(1-\mathcal{K}^m_{i,t}\right)\left(z^m_{i,t-1}+\sigma_m^2\right)\\
z^a_{i,A,t} &= \left(1-\mathcal{K}^a_{i,A,t}\right)\left(z^a_{i,A,t-1}+\sigma_a^2\right)\\
z^a_{i,B,t} &= \left(1-\mathcal{K}^a_{i,B,t}\right)\left(z^a_{i,B,t-1}+\sigma_a^2\right)
\end{aligned}
$$

and

$$\mathcal{K}^m_{i,t} = \frac{z^m_{i,t-1} + \sigma^2_m}{z^m_{i,t-1} + \sigma^2_m + \eta^2_{i,m,t}},\ \mathcal{K}^a_{i,A,t} = \frac{z^a_{i,A,t-1} + \sigma^2_A}{z^a_{i,A,t-1} + \sigma^2_A + \eta^2_{i,A,t}},\ \mathcal{K}^a_{i,B,t} = \frac{z^a_{i,B,t-1} + \sigma^2_B}{z^a_{i,B,t-1} + \sigma^2_B + \eta^2_{i,B,t}}.$$

Then

$$\begin{aligned}
\eta^2_{i,m,t} &= \frac{z^m_{i,t}\left(z^m_{i,t-1} + \sigma^2_m\right)}{z^m_{i,t-1} + \sigma^2_m - z^m_{i,t}} \\
\eta^2_{i,A,t} &= \frac{z^a_{i,A,t}\left(z^a_{i,A,t-1} + \sigma^2_a\right)}{z^a_{i,A,t-1} + \sigma^2_a - z^a_{i,A,t}} \\
\eta^2_{i,B,t} &= \frac{z^a_{i,B,t}\left(z^a_{i,B,t-1} + \sigma^2_a\right)}{z^a_{i,B,t-1} + \sigma^2_a - z^a_{i,B,t}}
\end{aligned}$$

5. Generate random numbers for signal noises $\xi_{i,m,t} \sim \mathcal{N}\left(0, \eta^2_{i,m,t}\right)$, $\xi_{i,A,t} \sim \mathcal{N}\left(0, \eta^2_{i,A,t}\right)$, $\xi_{i,B,t} \sim \mathcal{N}\left(0, \eta^2_{i,B,t}\right)$.

6. Calculate the perceived gap(markup) **after observing their signals** at t

$$\begin{aligned}
x_{i,A,t} &= x_{i,A,t-1} - \left[\mathcal{K}^m_{i,t}\left(s^m_{i,t} - m_{i,t-1|t-1}\right) + \mathcal{K}^a_{i,A,t}\left(s^a_{i,A,t} - a^a_{i,A,t-1|t-1}\right)\right] \\
&= x_{i,A,t-1} - \Big[\mathcal{K}^m_{i,t}\left(m_{t-1} - m_{i,t-1|t-1} + \varepsilon^m_t + \xi_{i,m,t}\right) \\
&\qquad + \mathcal{K}^a_{i,A,t}\left(a^a_{i,A,t-1} - a^a_{i,A,t-1|t-1} + \varepsilon^a_{i,A,t} + \xi_{i,A,t}\right)\Big]
\end{aligned}$$

$$\begin{aligned}
x_{i,B,t} &= x_{i,B,t-1} - \left[\mathcal{K}^m_{i,t}\left(s^m_{i,t} - m_{i,t-1|t-1}\right) + \mathcal{K}^a_{i,B,t}\left(s^a_{i,B,t} - a^a_{i,B,t-1|t-1}\right)\right] \\
&= x_{i,B,t-1} - \Big[\mathcal{K}^m_{i,t}\left(m_{t-1} - m_{i,t-1|t-1} + \varepsilon^m_t + \xi_{i,m,t}\right) \\
&\qquad + \mathcal{K}^a_{i,B,t}\left(a^a_{i,B,t-1} - a^a_{i,B,t-1|t-1} + \varepsilon^a_{i,B,t} + \xi_{i,B,t}\right)\Big]
\end{aligned}$$

where

$$\begin{aligned}
a_{i,A,t} - a_{i,A,t|t} &= \left(1 - \mathcal{K}^a_{i,A,t}\right)\left(a_{i,A,t-1} - a_{i,A,t-1|t-1}\right) + \varepsilon^a_{i,A,t} - \mathcal{K}^a_{i,A,t}\left(\varepsilon^a_{i,A,t} + \xi_{i,A,t}\right) \\
a_{i,B,t} - a_{i,B,t|t} &= \left(1 - \mathcal{K}^a_{i,B,t}\right)\left(a_{i,B,t-1} - a_{i,B,t-1|t-1}\right) + \varepsilon^a_{i,B,t} - \mathcal{K}^a_{i,B,t}\left(\varepsilon^a_{i,B,t} + \xi_{i,B,t}\right) \\
m_t - m_{i,t|t} &= \left(1 - \mathcal{K}^m_{i,t}\right)\left(m_{t-1} - m_{i,t-1|t-1}\right) + \varepsilon^m_t - \mathcal{K}^m_{i,t}\left(\varepsilon^m_t + \xi_{i,m,t}\right)
\end{aligned}$$

with given $a_{i,A,-1} - a_{i,A,-1|-1} = 0$, $a_{i,B,1} - a_{i,B,-1|-1} = 0$, and $m_{-1} - m_{i,-1|-1} = 0$.

7. Price changes: for $j = \{A, B\}$,

$$\Delta p_{i,j,t} = \begin{cases} 0 & \text{if } -\theta + \beta V\left(0, 0, z^a_{i,A,t}, z^a_{i,B,t}, z^m_{i,t}\right) \\ & \qquad \leq -\left[(x_{i,A,t})^2 + (x_{i,B,t})^2\right] + \beta V\left(x_{i,A,t}, x_{i,B,t}, z^a_{i,A,t}, z^a_{i,B,t}, z^m_{i,t}\right) \\ -x_{i,j,t} & \text{if } -\theta + \beta V\left(0, 0, z^a_{i,A,t}, z^a_{i,B,t}, z^m_{i,t}\right) \\ & \qquad > -\left[(x_{i,A,t})^2 + (x_{i,B,t})^2\right] + \beta V\left(x_{i,A,t}, x_{i,B,t}, z^a_{i,A,t}, z^a_{i,B,t}, z^m_{i,t}\right) \end{cases}$$

8. True markup: for $j = \{A, B\}$,

$$\begin{aligned} \mu_{i,j,t} &= p_{i,j,t} - m_t - a_{i,j,t} \\ &= \Delta p_{i,j,t} + x_{i,j,t-1} - \left(m_{t-1} - m_{i,t-1|t-1}\right) - \left(a_{i,j,t-1} - a_{i,j,t-1|t-1}\right) - \varepsilon^m_t - \varepsilon^a_{i,j,t} \end{aligned}$$

where $a_{i,j,-1} - a_{i,j,-1|-1} = 0$ and $m_{-1} - m_{i,-1|-1} = 0$.

C Additional Tables and Figures

Table A.1: Summary Statistics for Number of Products

Industries	Obs.	Mean	Median	Std. Dev.	Max.
Total	712	67.4	9	234.2	2115
Total without Retail/Wholesale Trade	627	9.55	7	8.47	48
– Manufacturing	278	9.57	8	7.75	39
– Professional and Financial Services	276	7.95	7	6.09	35
– Other Services	37	14.49	13	11.63	48
– Construction and Transportation	36	8.42	5	8.92	40

Notes: This table reports summary statistics for firms' number of products by sectors. The number of products of each firm is measured from answers to the following question in the second wave of New Zealand Firms' Expectation Survey: "*In addition to your main product or product line, how many other products do you sell?*" See Coibion et al. (2018a) for details about the survey data. Moments are calculated using sampling weights.

Table A.2: Summary Statistics for (Absolute) Backcast Errors about Inflation by Industries

Industries	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
	N	Mean (S.D.)	*N*	Mean (S.D.)	*N*	Mean (S.D.)	*N*	Mean (S.D.)
Total	1-4	5.01 (4.56)	5-9	5.83 (4.93)	10-15	3.89 (5.20)	>15	2.47 (2.99)
Total without Retail/Wholesale	1-3	5.23 (4.10)	4-7	6.30 (5.03)	8-14	4.40 (5.57)	>14	3.53 (3.62)
– Manufacturing	1-4	1.52 (2.19)	5-8	1.70 (1.86)	9-14	2.25 (2.74)	>14	2.46 (2.56)
– Professional and Financial Services	1-3	6.42 (3.17)	4-8	6.16 (4.65)	9-12	7.00 (3.57)	>12	5.51 (3.71)
– Other Services	1-5	2.29 (1.97)	6-13	0.72 (0.46)	14-21	0.76 (0.52)	>21	0.90 (0.51)
– Construction and Transportation	1-3	7.46 (5.06)	4-5	7.38 (4.55)	6-9	10.82 (5.34)	>9	7.36 (7.59)

Notes: This table reports summary statistics for firms' (absolute) backcast errors about aggregate inflation by quartiles of the distribution of the number of products in each industry. The backcast errors are the absolute value of firm errors about past 12 month inflation from Wave #1 survey. Moments are calculated using sampling weights.

Table A.3: Number of Products and Knowledge about Aggregate Inflation (All Industries)

	(1)	(2)	(3)	(4)
Panel A. Dependent variable: Inflation backcast errors				
log(# of products)	-0.401***	-0.103***	-0.210***	-0.0565*
	(0.069)	(0.030)	(0.063)	(0.033)
Observations	670	656	504	492
R-squared	0.225	0.835	0.269	0.897
Panel B. Dependent variable: Willingness to pay for professional inflation forecasts				
log(# of products)	-2.391	2.924**	-3.548**	3.884***
	(1.852)	(1.224)	(1.607)	(1.185)
Observations	436	429	375	373
R-squared	0.101	0.624	0.190	0.640
Firm-level controls	Yes	Yes	Yes	Yes
Industry FE		Yes		Yes
Manager controls			Yes	Yes

Notes: This table reports results for the Huber robust regression. Dependent variables are the absolute value of firm errors about past 12 month inflation from Wave #1 survey (Panel A) and firms' willingness to payment for professional forecaster's forecasts about future inflation from Wave #4 (Panel B). Firm-level controls include log of firms' age, log of firms' employment, foreign trade share, number of competitors, firms' beliefs about price difference from competitors, and the slope of the profit function. Industry fixed effects include dummies for 17 sub-industries. Manager controls include the age of the respondent (each firm's manger), education, income, and tenure at the firm. Sample weights are applied to all specifications. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively.

Table A.4: Model Predictions and Monetary Non-Neutrality

	Menu Costs	Calvo/Taylor	Rational Inattention	Sticky/Noisy Info/ Observational Costs
1) Attentiveness to Aggregate Conditions	Full information	Full information	Increase in N	Independent of N
2) Size/Duration of Price Changes	Decrease in N	Independent of N	Flexible micro price	Independent of N
Monetary Non-Neutrality	Increase in N	Independent of N	Decrease in N	Independent of N

Notes: This table shows the predictions from different models about 1) the relationship between firms' number of products and their attentiveness to aggregate condition and 2) the relationship between firms' number of products and the duration and size of price changes. N stands for the number of products that firms sell in each model. See section 2.3 for details.

Table A.5: Number of Products and Knowledge about Nominal GDP Growth

	(1)	(2)	(3)	(4)
Dependent variable: Backcast errors about nominal GDP growth rate				
# of products	-0.033**	-0.025***	-0.032**	-0.026**
	(0.015)	(0.009)	(0.014)	(0.011)
Observations	387	380	332	328
R-squared	0.354	0.569	0.364	0.577
Firm-level controls	Yes	Yes	Yes	Yes
Industry FE		Yes		Yes
Manager controls			Yes	Yes

Notes: This table reports results for the Huber robust regression. Dependent variables are the absolute value of firm errors about the growth rate of nominal GDP from Wave #4 survey. Firms' perceived growth rate of nominal GDP are calculated by taking the summation of firms' belief about current inflation and the real GDP growth rate in New Zealand. Firm-level controls include log of firms' age, log of firms' employment, foreign trade share, number of competitors, firms' beliefs about price difference from competitors, and the slope of the profit function. Industry fixed effects include dummies for 14 sub-industries excluding retail and wholesale trade sectors. Manager controls include the age of the respondent (each firm's manger), education, income, and tenure at the firm. Sample weights are applied to all specifications. Robust standard errors (clustered at the 3-digit ANZ SIC level) are reported in parentheses. ***, **, * denotes statistical significance at 1%, 5%, and 10% levels respectively.

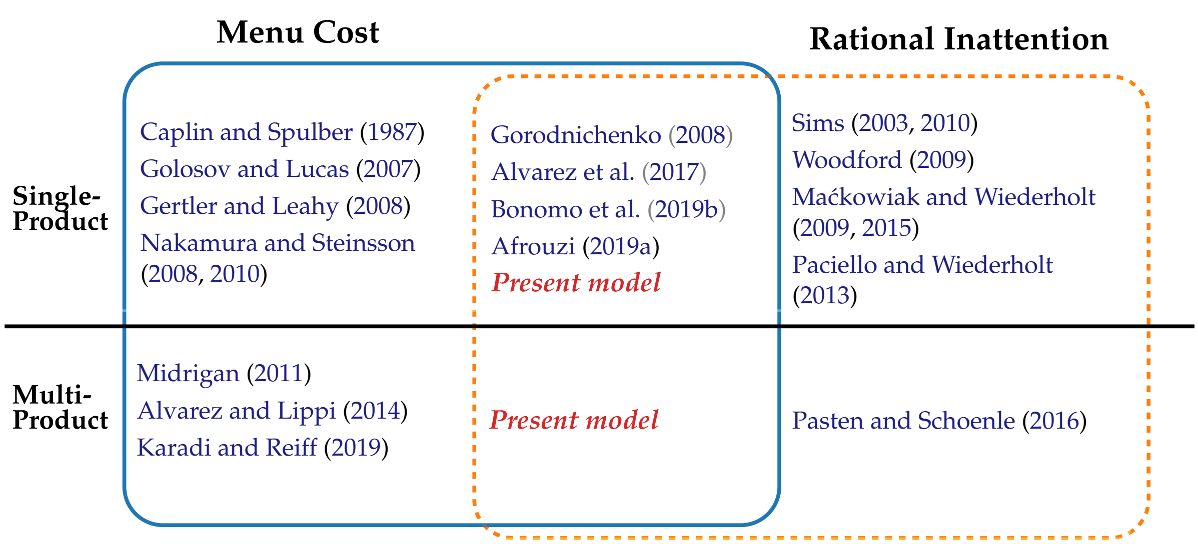


Figure A.1: Classification of Models

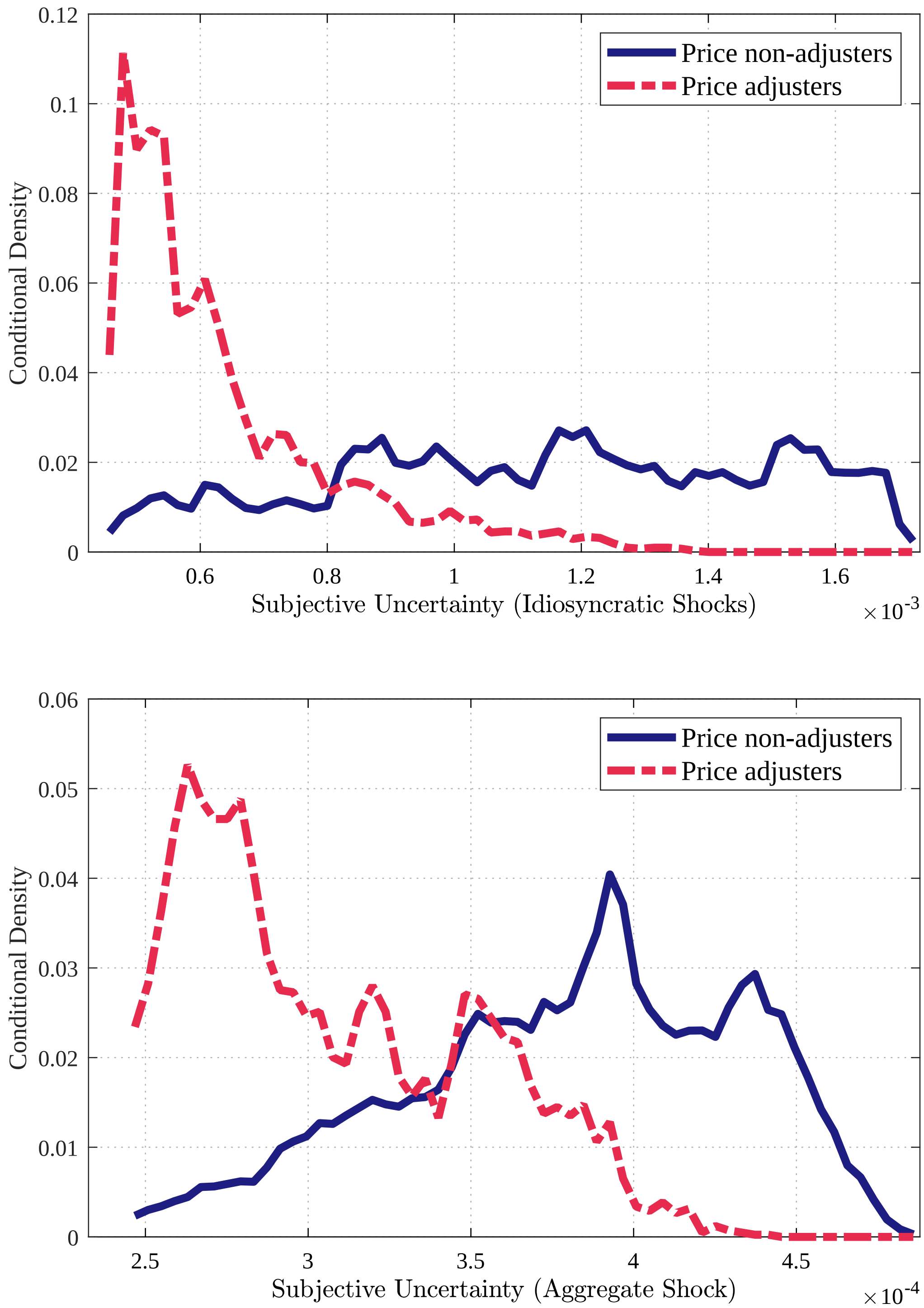


Figure A.2: Distribution of Subjective Uncertainty about the Idiosyncratic and Aggregate Shocks: Single-Product Baseline Model

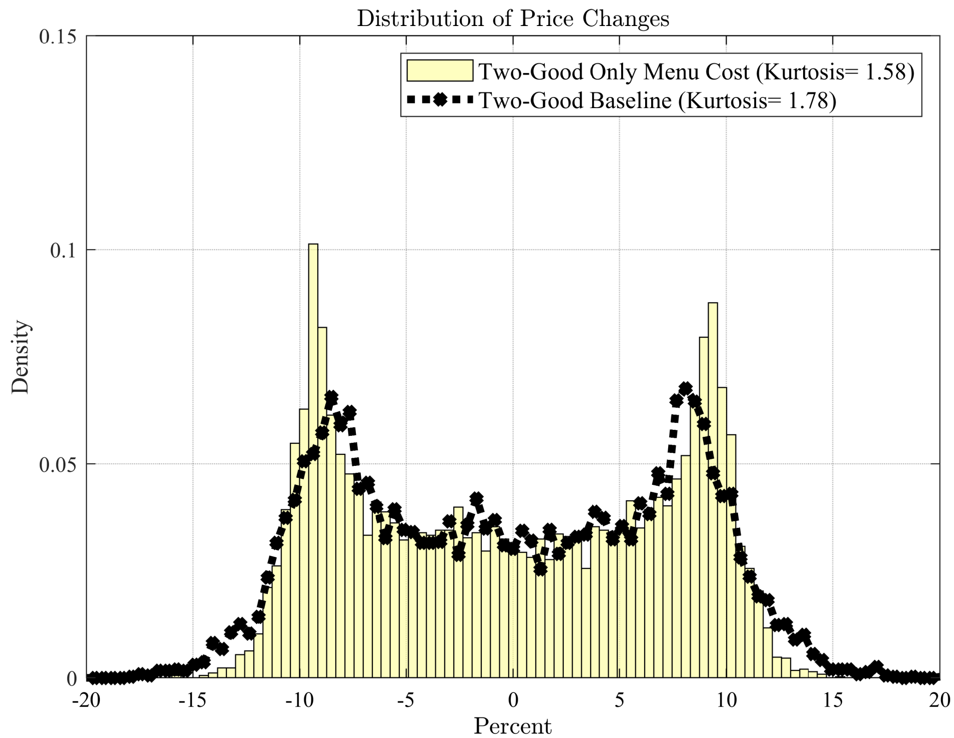


Figure A.3: Distribution of Price Changes in the Two-Product Models

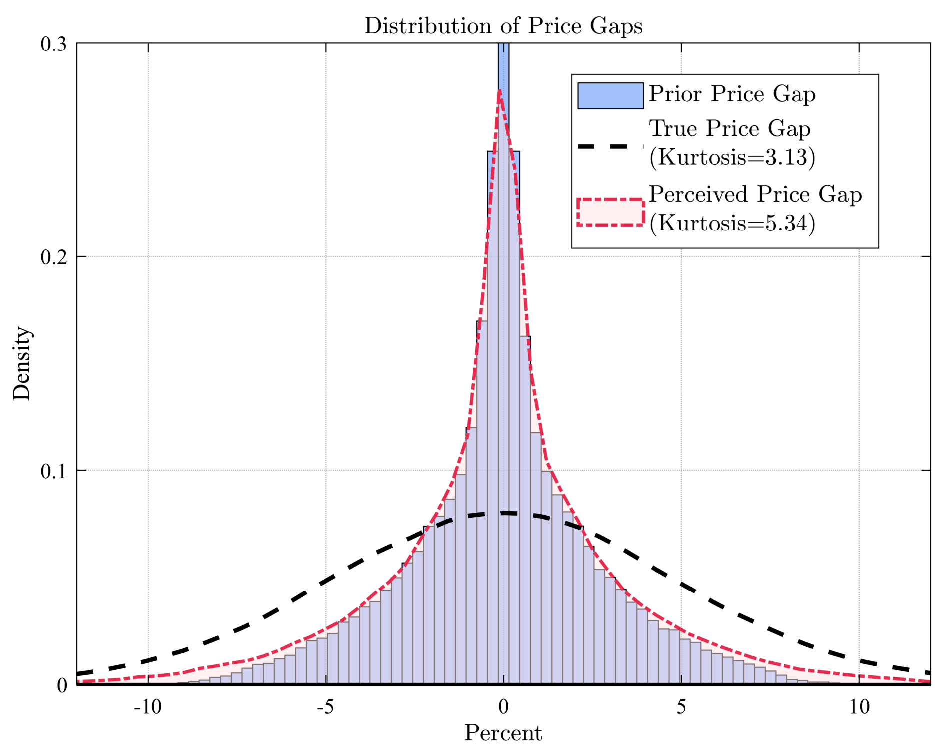


Figure A.4: Distribution of True and Perceived Price Gaps in the Two-Product Baseline Model

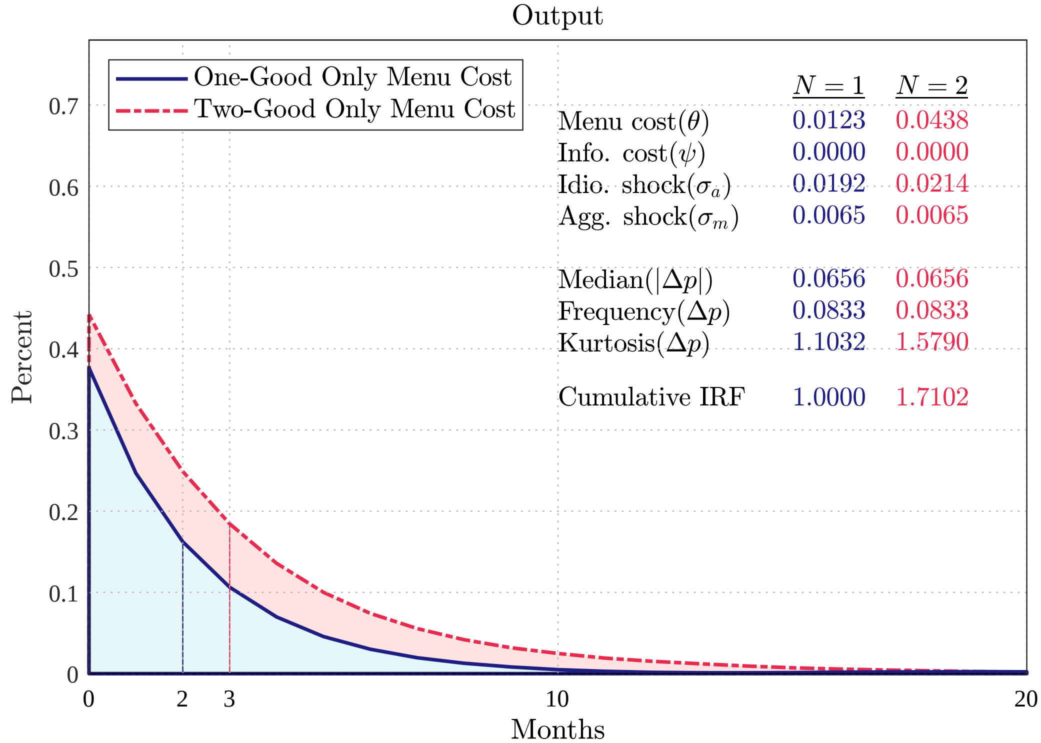


Figure A.5: Impulse Response of Output to a One S.D. Monetary Policy Shock in the Only Menu Costs Models

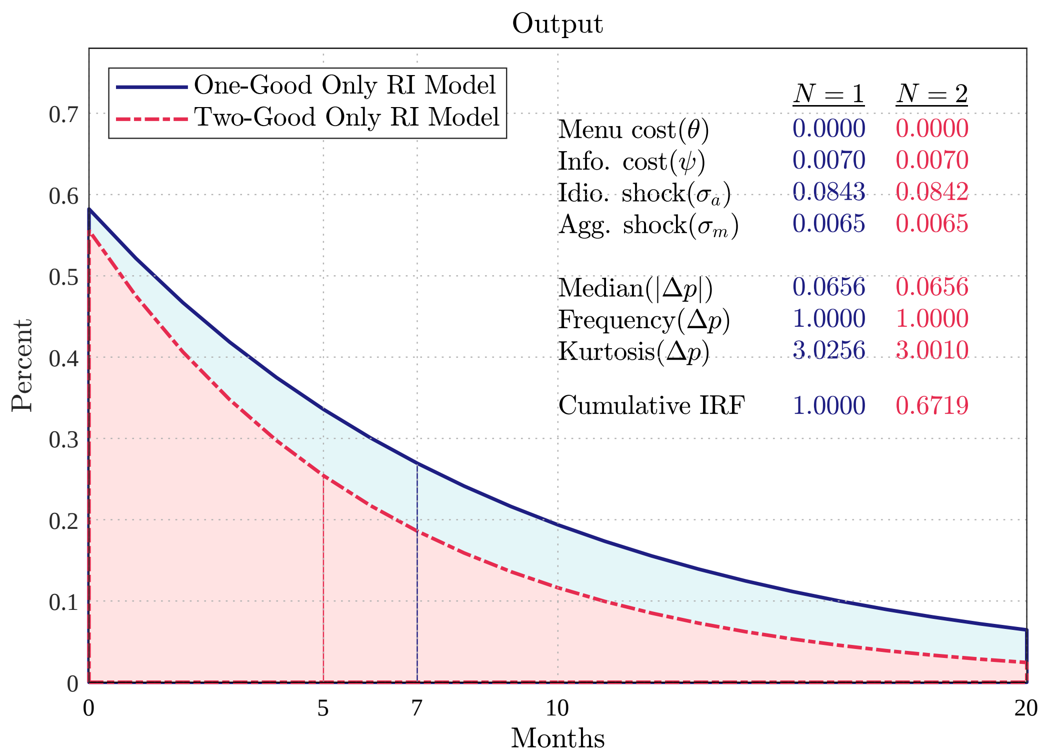


Figure A.6: Impulse Response of Output to a One S.D. Monetary Policy Shock in the Only Rational Inattention Models

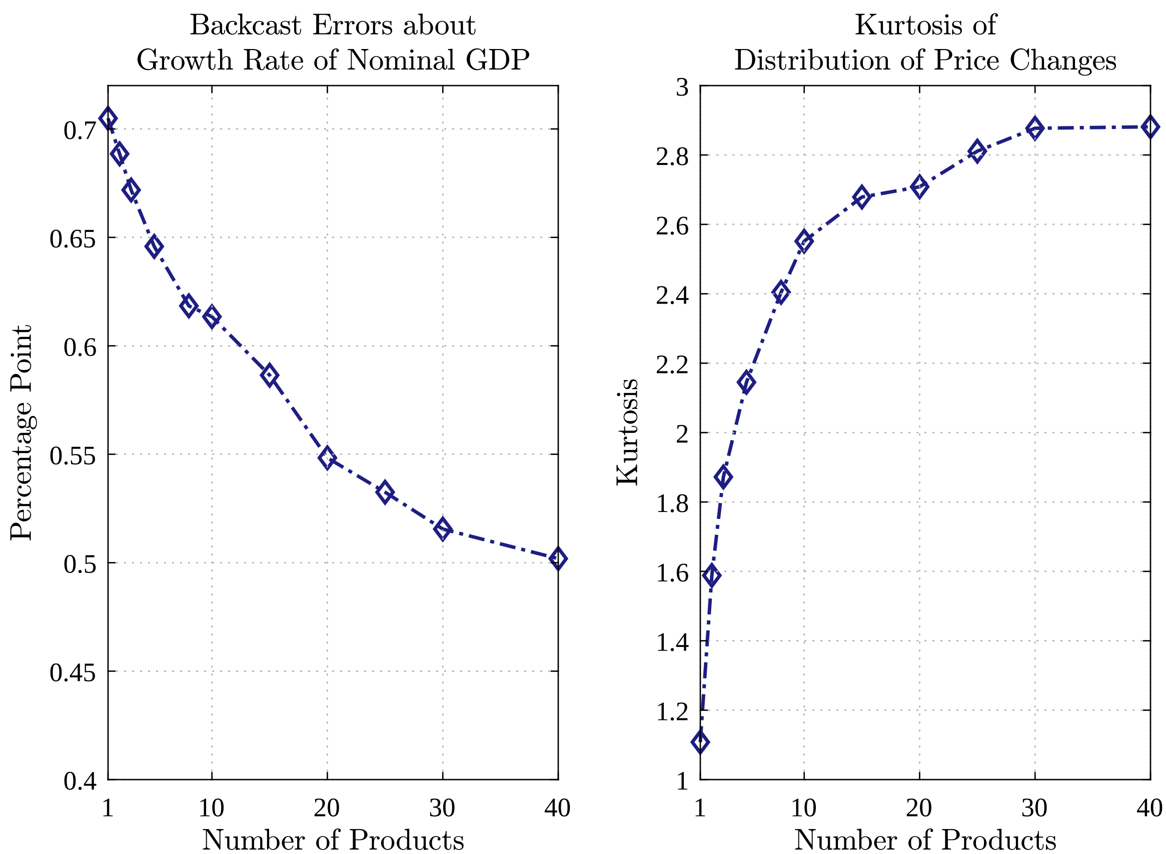


Figure A.7: Backcast Errors about Nominal GDP Growth and Kurtosis of Price Change Distribution