The Markup Elasticity of Monetary Non-Neutrality*

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Abstract

Firms' market powers, measured by markup, have risen substantially in the past decades and have become more dispersed across sectors. This paper develops a quantitative menu cost model to assess the implications of these trends for the real effects of monetary policy. The model features multiple sectors with heterogeneous degrees of market competition. Two quantitative results stand out. First, the average markup elasticity of monetary non-neutrality in the United States is equal to 1 in the past three decades. That is, the thirty percent increase in markup in the data raises monetary non-neutrality by thirty percent. Second, the increased dispersion of sectoral markups acts as a counterforce: the markup elasticity of monetary non-neutrality would be equal to 1.5 had the markup increased equally across sectors. These two results are due to the declined frequency of firms' price adjustment from increased market power and the concave relationship between markups and monetary non-neutrality.

Keywords: Rising market power, Monetary non-neutrality, Menu cost model, Heterogeneous market power, Multi-sector model

JEL Classification:

*The views expressed in this paper are those of the authors and they do not necessarily coincide with the views of Bank of Italy. All remaining errors are our own.

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1. Introduction

Firms' market power (market competition) has increased (decreased) substantially in the past decades: the aggregate markup in the United States increased from 20% in 1980 to nearly 60% today (De Loecker et al. 2020). Moreover, the changes in markups are heterogeneous across sectors. These trends affect firms' price-setting strategies. When making pricing decisions, firms balance the fixed adjustment cost—menu cost—with the benefits of adjusting prices. Market competition affects the benefits, and therefore, it alters firms' price-setting rules. Consequently, market power affects the potency of monetary policy since the latter depends on the responses of prices to monetary actions. The current paper assesses the discussed hypothesis formally. More specifically, we ask the following questions. How does monetary non-neutrality change with the recent trend in the aggregate markup? What is the aggregate markup elasticity of monetary non-neutrality? Does the heterogeneous sectoral evolution of markups matter for the aggregate monetary non-neutrality?

This paper addresses those questions based on a multi-sector menu cost model with heterogenous marker powers across sectors. We show that the recent increase in the aggregate markup has led firms to adjust prices less frequently, rendering monetary policy more effectively stimulating real economic activities. Specifically, our quantitative analysis suggests the average markup elasticity of monetary non-neutrality is equal to 1. Moreover, the increased dispersion in market power across sectors reduces the markup elasticity of monetary non-neutrality. The paper formulates the findings based on the following steps.

First, we build a *multi-sector* menu cost model that features random menu costs and leptokurtic idiosyncratic productivity shocks to generate realistic distribution of price changes. Importantly, the model allows for heterogenous desired markups (market power) across sectors. More specifically, firms operate in different sectors that are subject to different degree of market competition. The latter is proportional to the elasticity of substitution across goods within a sector.

Second, we calibrate the model to match pricing and markup moments in the U.S. data and use it as the laboratory to address the raised questions. The pricing and markups moments are matched and aggregated to the industry level, which is an additional contribution of the current paper useful for the calibration of this class of models. The model makes the following quantitative predictions. First, since 1980, monetary non-neutrality has increased by nearly 30% due to the increase in aggregate monetary non-neutrality of the same magnitude. The average markup elasticity of monetary non-neutrality is equal to one in the past decades. Second, through the lens of the model, we show that the sectoral markup dispersion documented in the data matters for monetary non-neutrality. In a counterfactual analysis, we show that had the dispersion in the moving average markups across sectors remained at its level in 1980, the increase in the aggregate markup would have raised monetary non-neutrality by 44%. The resulting aggregate markup elasticity of monetary non-neutrality is 1.5 the size compared to the case implied by the data where the increase in the aggregate markup is accompanied by increased cross-sector dispersion of markups. In addition, we find that monetary non-neutrality in a twenty-sector model with heterogenous steady-state markups is about 30% lower than the one-sector model and about 20% lower than the multi-sector model with homogeneous market powers.

We discuss the mechanism behind the quantitative findings. In a menu cost model, the effects of monetary (nominal stimulus) policy on real GDP are negatively related to the adjustment of the aggregate price to monetary policy. We show that market competition affects both the *intensive* and the *extensive* margin of monetary policy on prices. The intensive margin of the monetary policy refers to the effects of a nominal stimulus policy on the prices of the firms that would choose to adjust prices even in the absence of the monetary action. The intensive margin is proportional to the frequency of firms' price adjustment. We show that reduced market competition, i.e., a higher markup, decreases the frequency of firms' price adjustment. Therefore, the effects of monetary policy on prices are reduced at the intensive margin. Through this channel, monetary non-neutrality increases in the market power.

Through the extensive margin of monetary policy, monetary non-neutrality increases in the desired markup. The extensive margin of the monetary policy refers to the changes in the prices of those marginal firms who would not adjust prices in the absence of monetary policy shocks. The strength of the extensive margin depends on the mass of firms at the margin of adjusting prices. The latter depends on the distribution of price gaps—the gaps between the actual and the desired prices—and the Ss band that characterizes the non-adjusting region.[1] The degree of competitiveness in the goods market affects both the distribution of the price gap and the width of firms' Ss bands. Therefore, a reduced market competition increases monetary non-neutrality through the extensive margin.

Moreover, we show that the monetary non-neutrality in the model is an increasing *concave* function of the desired markups both through the intensive and extensive margins. This concave relationship, combined with the fact that the increase in the aggregate markup and its cross-sector dispersion is mostly driven by a few sectors, explains the implications of markup dispersions for the aggregate monetary non-neutrality discussed above.

[1] Formally, the Ss band is defined as the interval between the upper and the lower bounds of price gap values within which a firm does not adjust its price.

Literature Review Two recent papers have sparked interest in modeling the relationship between market competition and monetary non-neutrality. Mongey (2021) show that the aggregate monetary non-neutrality is higher in a model with oligopoly competition compared to the one with monopolistic competition, everything else equal. In a more related paper in terms of research questions, Wang and Werning (2020) find that higher market concentration, hence a higher market power, significantly amplifies the real effects of monetary policy in a model where firms play a Bertrand dynamic game but with stylized *Calvo* nominal rigidity. With Calvo pricing, by construction, the frequency of firms' price adjustment is fixed and is unrelated to market power. The current paper maintains the standard assumption in the macroeconomic literature: monopolistic competition. Compared to Wang and Werning (2020), we address a similar question but in a framework where market power is endogenously related to the frequency of price adjustment. Interestingly, the different mechanisms produce a similar finding: increased markup power enhances the potency of monetary policy. Moreover, we quantify the markup elasticity of monetary non-neutrality.[2]

This paper is closely related to the literature that employs the menu cost as a microfoundation for price rigidity: Dotsey et al. (1999), Golosov and Lucas (2007), Gertler and Leahy (2008), Midrigan (2011), Vavra (2014), Alvarez et al. (2016), Karadi and Reiff (2019) and Alvarez et al. (2021). The existing literature focuses on pricing moments and their relationships with monetary non-neutrality. For example, Alvarez et al. (2016) provide a sufficient statistics from the price-change distribution for the aggregate monetary non-neutrality in a large class of models. However, pricing moments are endogenous, understanding the determinant of the price-change distribution is relevant. The literature has uncovered that the distribution of shocks affect the pricing moments (Midrigan 2011 and Karadi and Reiff 2019). The current paper contributes to this line of research by demonstrating that market power is an important determinant of distribution of price-change distribution and by quantifying the markup elasticity of monetary non-neutrality.[3]

This paper is related to the literature that emphasized the relevance of sectoral heterogeneity in price rigidity for the aggregate monetary non-neutrality: see e.g., Carvalho (2006), Nakamura and Steinsson (2010), Carvalho and Schwartzman (2015), Gautier and Bihan (2018), Carvalho et al. (2020), and Pasten et al. (2020). The current paper shows

[2] Meier and Reinelt (2022) show that firms with more rigid prices optimally set higher markups due to the precautionary price-setting motive. Their paper takes the degree of price rigidity as given which in our paper is endogenous. In addition, they focus on markups at the business cycle frequency while our focus is on the steady state markups.

[3] In this literature, our framework is closest to Li (2022). The novelty of the current paper is to introduce multiple sectors with heterogenous market powers across sectors that are crucial for the quantitative analysis.

that heterogeneity in sectoral market power is another important determinant of monetary non-neutrality.

2. Motivating Facts

This section reproduces the empirical findings uncovered by De Loecker et al. (2020). We highlight the cross-sector heterogeneity in markup development.

2.1 Data

In this section we outline the data we use for the empirical analysis and in order to calibrate our theoretical model. Our data building process combines data from two different data sources and uses a new crosswalk we build by hand. We construct crosswalks from the ELI product category of CPI prices to NAICS industries. The matches are made by hand according to a comparison of the industry categories and the product descriptions.

Firm-Level Markups We use quarterly firm-level balance-sheet from 1980 - 2016 of publicly traded firms in Compustat to calculate firm-level markups. The data covers sales, employment, capital, and input factors of firms (cost of goods sold) over a long sample for a wide range of sectors covering not only manufacturing but also service sector firms. We estimate firm-level markups following the single-input approach (De Loecker and Warzynski 2012). According to this approach, the markup $\mu_{i,t}$ of a firm i at time t can be computed from one flexible input, X_i, as the ratio of the output elasticity of the input, ϵ_{Q,X_i}, to the revenue share of that input, s_{R,X_i}

$$\mu_{i,t} = \frac{\epsilon_{Q,X_i}}{s_{R,X_i}}. \tag{1}$$

Compustat reports a composite input called Cost of Goods Sold (COGS), which consists of intermediate and labor input and that will be used as the (partially) flexible input, X_i. The authors use a variant of the technique introduced by Olley and Pakes (1996) and described in De Loecker and Warzynski (2012) to estimate a Cobb-Douglas function and obtain a time-varying estimate of output elasticity at the sector level. The markups are then derived by dividing the former (estimated at the industry-year level) by the share of COGS to revenue (estimated at the firm-year level). In terms of implementation, we follow the procedure described in De Loecker et al. (2020) with the adjustments described in Baqaee and Farhi (2020). In particular, we estimate time-varying output elasticities and deflate using gross output price indices from KLEMS sector-level data.

When transforming the data, we drop all firms in the government sector or the sector of the economy composed of finance, insurance, and real estate. We consider only observations that are positive and linear interpolate observations that are missing for one period. Additionally, we perform outlier adjustments by trimming at 1% (5%) of calculated markups.

One concern with Compustat is that it covers only publicly traded firms and thus is not representative of the distribution of the universe of firms. We account for a representativeness bias by using the weights of each sector in the Compustat data from the PCE expenditure shares to account for sectoral composition (while we still calculate markups from publicly traded firms).

Smoothed Markups The markups at the sectoral level ($\mu_{k,t}$) are the weighted average of firm level markups using firms' sale share as the weight. We compute the smoothed markup ($\mu^{ss}_{k,t}$) for an industry k at time t as the seven-year moving average of $\mu_{k,t}$ centered at year t.[4]

2.2 Empirical Results: Markup Dispersions

Figure 7 confirms, both qualitatively and quantitatively, the overall increase in the aggregate markup documented by De Loecker et al. (2020). The smoothed aggregate markup raised from 1.2 in 1980 to 1.55 now—a nearly 30% increase. The current paper focuses on three observations related to cross-sector dispersions in markups.

Observation 1: Markups are Dispersed Figure 1 plots the smoothed markups at industry level over time: See Panel (a) for eight one-digit NAICS sectors and Panel (b) for twenty two-digit NAICS sectors. The computed smoothed markups are very heterogenous across sectors independent of the year of the observation. For example, in year 2000, the steady-state markup ranges from nearly 1 to about 1.6 across industries, a difference of 60%.

Observation 2: Markup Dispersion Increases over time The second observation that we highlight is the increase in the dispersion of smoothed markups across sectors. This observation is clearly identified in Panels (c) and (d) in Figure 1. The standard deviation and the interquantile range of smoothed markups across sectors are computed for each

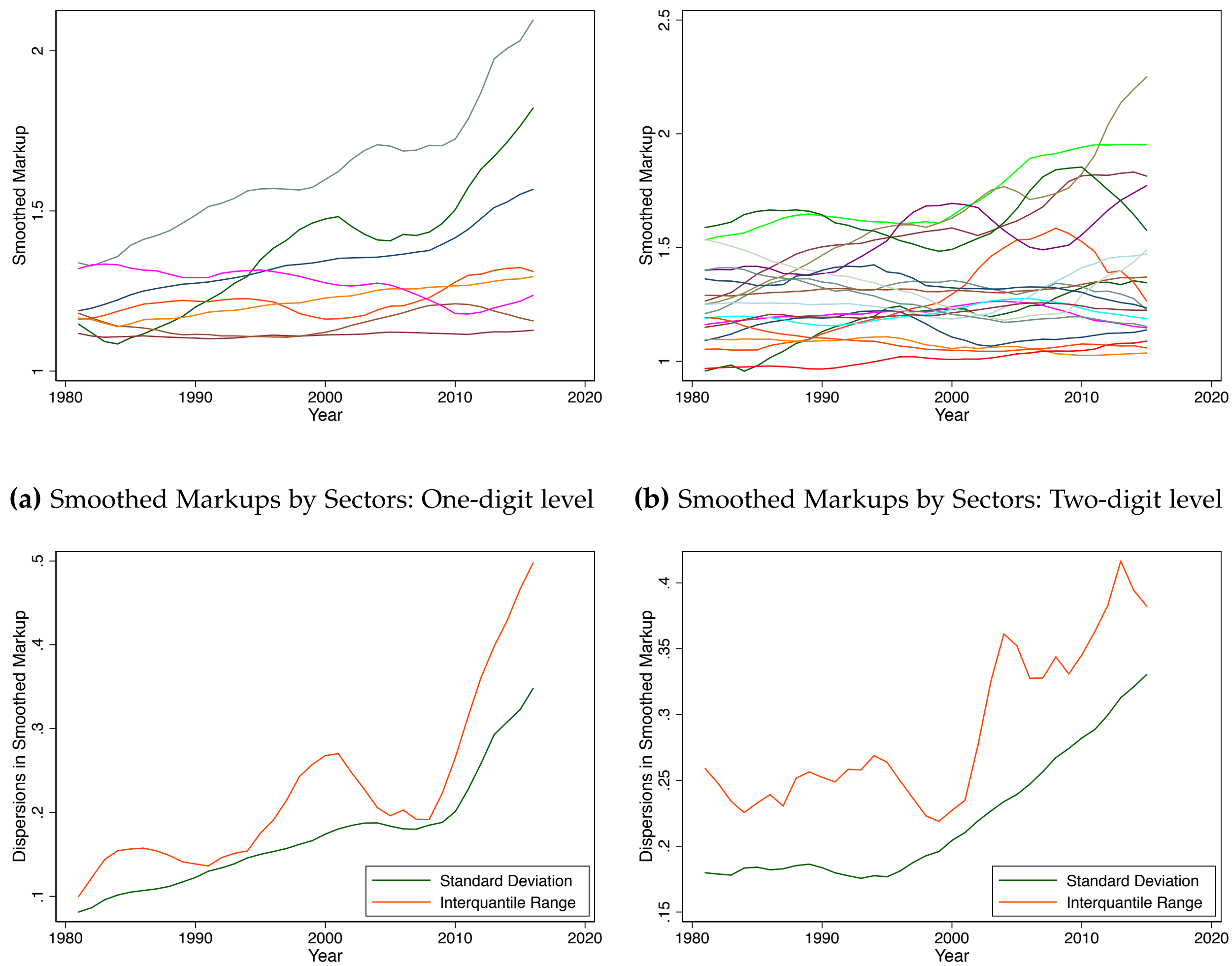
[4] All results presented in the paper are robust to the use of alternative length of moving average.

year and are plotted in Panel (c) for the one-digit NAICs classification case and Panel (d) for the two-digit NAICs classification case. The standard deviation (interquantile range) of smoothed markups across the one-digit NAICS classified industries increased from 0.1 in 1980 to 0.35 (0.5) in 2016. The constructed measures of dispersion in smoothed markups have more than tripled over the past decades.

Observation 3: The Dominance of the Right Tail The changes in the right tail of the cross-sector markup distribution are driving the increase in the aggregate markup and the dispersion. This can be seen in Panel (a) and (b) in Figure 1 (see also the red lines in Figure 8 that plot the evolution of the smoothed markups by sector). In the eight sector case, the increase in the aggregate markup documented in Figure 7 is driven by three sectors that saw shape rises in markups. Markups in the other sectors remained relatively stable, with one sector seeing a drop in markup. As a result, the cross-sector dispersion in smoothed markups increases.

In the remainder of the paper, we investigate the implications of those three observations for monetary non-neutrality based on a multi-sector menu cost model with heterogenous cross-sector market powers.

Figure 1: Markups and Markup Dispersions



(a) Smoothed Markups by Sectors: One-digit level **(b)** Smoothed Markups by Sectors: Two-digit level

(c) Smoothed Markup Dispersions across Sectors at One-digit level **(d)** Smoothed Markup Dispersions across Sectors at Two-digit level

Note: Authors' own calculation. This figures plots steady-state markups (measured as cost share) in Compustat from 1980-2017 for the one-digit and the two-digit NAICS sectors, as well as their dispersions.

3. A Multi-sector Model with Heterogeneous Markups

In this section, we construct a multi-sector menu cost model. The model contains the standard ingredients of a second-generation menu cost model, such as random menu costs and leptokurtic idiosyncratic productivity shocks, to generate realistic distribution of price changes, see, e.g., Vavra (2014), Karadi and Reiff (2019) and Alvarez et al. (2021). Motivated by the empirical observations, our main methodological innovation is to incorporate heterogeneous sectoral market powers into this class of model.

3.1 Household

There is a representative household and a continuum of monopolistically competitive firms, indexed by (K, i), where K is the number of sections and $i \in [0, 1]$. The preference of the representative household is given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} + \kappa \frac{N_t^{\psi}}{1-\psi} \right], \tag{2}$$

where β is the discount factor, κ controls the magnitude of disutility from working, γ is the elasticity of inter-temporal substitution and ψ is the inverse of the Frisch elasticity. Aggregate labor supply is represented by N_t and aggregate consumption bundle is denoted by C_t, defined as:

$$C_t = (\sum_{k=1}^{K} \omega_k^{\frac{1}{\eta}} C_{k,t}^{\frac{\eta-1}{\eta}})^{\frac{\eta}{\eta-1}}, \tag{3}$$

where η is the elasticity of substitution over goods across sectors and $\{\omega_k\}$ are the sectoral weights. The final good in sector k is given by:

$$C_{k,t} = \omega_k \left(\int_{i \in [0,1]} c_{k,i,t}^{\frac{\theta_k - 1}{\theta_k}} di \right)^{\frac{\theta_k}{\theta_k - 1}}, \tag{4}$$

where θ_k is the elasticity of substitution over goods within sector k. The inter-temporal budget constraint of the household at period t is:

$$\sum_{k=1}^{K} \int p_{k,i,t} c_{k,i,t} dj + Q_{t+1} B_{t+1} \leq B_t + W_t N_t + \Pi_t, \tag{5}$$

Here, $p_{i,j,t}$ is the price of goods produced by firm i in sector k at period t, W_t is the wage rate, Q_{t+1} is the price of state-contingent nominal bonds, and Π_t are the profits from all firms.

Household's Optimality Conditions The representative household chooses consumption bundle $\{c_{k,i,t}\}$, labor supply N_t and holdings of nominal bonds B_{t+1} to maximize their sum of discounted expected utility expressed in (2), subject to the budget constraints (5).

Solving this problem gives the demand for differentiated goods, the inter-temporal Euler equation and an intra-temporal equation for aggregate labor supply:

$$c_{k,i,t} = \left(\frac{p_{k,i,t}}{P_{k,t}}\right)^{-\theta_k} \left(\frac{P_{k,t}}{P_t}\right)^{-\eta} C_t, \tag{6}$$

$$Q_{t+1} = \beta \frac{P_t C_t}{P_{t+1} C_{t+1}} \tag{7}$$

$$\frac{W_t}{P_t} = \kappa C_t, \tag{8}$$

The sectoral price index ($P_{k,t}$) and the aggregate price index (P_t) are defined as:

$$P_{k,t} = \left(\int p_{k,i,t}^{1-\theta_k} di\right)^{\frac{1}{1-\theta_k}}, \tag{9}$$

$$P_t = \left(\sum_{k=1}^{K} \omega_k P_{k,t}^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{10}$$

It is important to note that allowing the elasticity of substitution to vary across sectors is equivalent to assuming heterogeneous degree of competitiveness in goods market across sectors. That is, firms operate in different sectors have different market powers with different desired (steady-state) markups. Formally, the desired markup for firms in a sector k is defined $\frac{\theta_k}{\theta_k - 1}$ $\forall \theta_k \in (1, \infty)$. The desired markup decreases in the degree of competitiveness measured by θ_k. In the limiting case, as θ_k converges to ∞, the market converges to a perfect competitive market. This paper corresponds the smoothed markups in the data to the steady-state markups in the model.

3.2 Firms

The differentiated good $c_{k,i,t}$ is produced by firm i in sector k by hiring $n_{k,i,t}$ units of labor and using the following linear technology:

$$y_{k,i,t} = a_{k,i,t} n_{k,i,t}.$$

where $a_{k,i,t}$ is the idiosyncratic productivity of firm i in sector k, which evolves according to the following process:

$$\log a_{k,i,t} = \begin{cases} \rho_k^a \log a_{k,i,t-1} + \sigma_k^z \epsilon_{k,i,t}^a, & \text{with probability } \alpha_k \\ \log a_{k,i,t-1}, & \text{with probability } 1-\alpha_k, \end{cases} \tag{11}$$

where $\epsilon_{k,i,t}^z \sim N(0,1)$ is independent across firms. We denote the transition probability of this Markov chain as $\Pr_k\left(a_{k,i,t+1}|a_{k,i,t}\right)$.

We assume that firms adjust prices with random menu costs: In every period, with probability ϕ_k, firms can adjust their prices freely. Otherwise firms pay fixed costs $\overline{f}_{k,i}$ in units of labor to change their nominal prices. To summarize, the menu cost $f_{k,i,t}$ is given by:

$$f_{k,i,t} = \begin{cases} 0, & \text{with probability } \phi_k \\ \overline{f}_{k,i}. & \text{with probability } 1-\phi_k \end{cases} \tag{12}$$

Firms' Optimality Conditions Firm i in sector k chooses its prices to maximize total real discounted profits:

$$\max_{\{p_{k,i,t}\}} \; E_0 \sum_{t=0}^{\infty} q_{0,t}\pi_{k,i,t},$$

where $\pi_{k,i,t}$ is the real profit at period t and $q_{0,t} \equiv q_{0,1}q_{1,2}\ldots q_{t-1,t}$ discounts future profits into present value. Noe that $q_{t,t+1}$ is the real stochastic discount factor which satisfies $q_{t,t+1} = Q_{t+1}P_{t+1}/P_t$.

Let $\Gamma_{k,t}(p_{-1},a,f)$ be the distribution over idiosyncratic states in sector k at period t. We can formulate firms' decision problem recursively:

$$V_{k,t}(p_{k,i,t-1},a_{k,i,t},f_{k,i,t}) = \max_{p_{k,i,t}} \left\{u_{k,i,t} + \mathbb{E}q_t V_{k,t+1}(p_{k,i,t},a_{k,i,t+1},f_{k,i,t+1})\right\} \tag{13}$$

with

$$u_{k,i,t} \equiv \left(\frac{p_{k,i,t}}{P_t} - \frac{W_t}{a_{k,i,t}P_t}\right)c_{k,i,t} - \mathbb{1}_{\{p_{k,i,t-1}\neq p_{k,i,t}\}} f_{k,i,t}\frac{W_t}{P_t},$$

and subject to

$$P_{k,t} = \left(\int \left[\psi_{k,t}(p_{-1},a,f)\right]^{1-\theta_k} \mathrm{d}\Gamma_{k,t}(p_{-1},a,f)\right)^{\frac{1}{1-\theta_k}},$$

$$P_t = \left(\omega_k \sum_{k=1}^{K} P_{k,t}^{1-\eta} \right)^{\frac{1}{1-\eta}},$$

where $\psi_{k,t}(p_{-1}, a, f)$ is the policy function for $p_{k,i,t}$ of firms in sector k at period t, and demand $c_{k,i,t}$ is given by equation (6). The distribution $\Gamma_{k,t}(p_{-1}, a, f)$ evolves according to:

$$\Gamma'_{k,t+1}(\mathcal{B}, a', f') = \left[\phi_k \mathbb{1}_{\{f'=0\}} + (1-\phi_k) \mathbb{1}_{\{f'=\bar{f}\}} \right] \int_{\{(p_{-1},a):\ \phi_{k,t}(p,a,f) \in \mathcal{B}\}} \Pr_k(a'|a) d\Gamma_{k,t}(p_{-1}, a, f), \quad (14)$$

for all sets $\mathcal{B} \in \mathbb{R}$.

Note that the policy functions $\{\phi_{k,t}\}$ and the distributions $\{\Gamma_{k,t}\}$ are not stationary but vary over time since the aggregate shock is one-time and unexpected.[5] Let $\Gamma_t(p_{-1}, a, f)$ be the distribution over idiosyncratic states in the economy at period t. It is straightforward to show that:

$$\Gamma_t(p_{-1}, a, f) = \sum_{k=1}^{K} \omega_k \Gamma_{k,t}(p_{-1}, a, f) \quad (15)$$

3.3 The Central Bank

Following the tradition of the menu cost literature, we assume that the monetary authority controls the aggregate nominal spending $S_t = P_t C_t$, the log of which follows a random walk with drift:

$$\log S_t = \mu + \log S_{t-1} + \sigma_S \epsilon_t^S; \quad (16)$$

The current paper refers to ϵ_t^S as the monetary shock.

3.4 Equilibrium

Given the law of motions of exogenous shocks (11), (12) and the path of monetary policy shocks, an equilibrium of the economy consists of:

(i) the household's demand for differentiated goods $\{c_{k,i,t}\}$ given by condition (6) of households' decision problem,

(ii) firms' value functions $\{\{V_{k,t}\}_{k=1}^{K}\}_{t=0}^{\infty}$ and policy functions $\{\{\psi_{k,t}\}_{k=1}^{K}\}_{t=0}^{\infty}$, that solve firms' price-setting problem (13),

(iii) aggregate output C_t and sectoral outputs $\{C_{k,t}\}_{k=1}^{I}$ that satisfy equations (3) and (4),

[5] We consider one-time shocks instead of systematic monetary policy shocks (e.g. Nakamura and Steinsson (2010) because it is extremely difficult to reduce the infinite dimensional state variable (distribution of last-period prices) to a computationally feasible finite number of states.

(iv) aggregate price functions W_t, Q_t, $\{P_{k,t}\}_{k=1}^{K}$ and P_t that are determined by equations (8), (9) and (10),

(v) the distributions on firms' individual states $\{\{\Gamma_{k,t}(p_{-1}, a, f)\}_{k=1}^{K}\}_{t=0}^{\infty}$ that evolve according to (14) and $\{\Gamma_t(p_{-1}, a, f)\}_{t=0}^{\infty}$ is given by (15),

(vi) and the aggregate nominal spending $S_t = P_t C_t$.

3.5 Computation

In Section 5, we compute the transition path of the perfect foresight equilibrium in response to an unexpected monetary policy shock. We briefly describe the computational procedure. We first assume that the economy starts in the steady state and returns to it after 200 periods. We next guess the entire path of the sectoral prices over the transition path. Given these prices, we solve for firms' pricing problems backward. We then simulate firms in the economy forward using a non-stochastic simulation algorithm similar to Algan et al. (2008) to get the distribution over individual state variables at every period. Using this distribution and the firms' policy rules we compute the sectoral prices. If these prices are different from the guessed ones, we update the guessed prices until the equilibrium converges. In doing so, we obtain the aggregate and sectoral impulse response functions to the monetary policy shock.

4. Targeted Moments and Model Calibration

4.1 Frequency of Price Adjustment

One of the main source for empirical studies on the price-setting behavior on the microeconomic level is the CPI research data base at the Bureau of Labor Statistics, which contains the product level data used to construct the consumer price index (CPI). It has been used by Bils and Klenow (2004), Nakamura and Steinsson (2008), Bils et al. (2012) and Nakamura et al. (2018).

For the construction of our sectoral dataset, we use the data that Nakamura and Steinsson (2008) provide, which is readily available, covers manufacturing and services sectors and focuses on a period with low inflation (1998-2005).[6] The data consists of the monthly average fraction of prices that changes for 270 Entry Level Items (ELIs) in the non-shelter component of the CPI over the period 1998-2005. The CPI is constructed at the BLS by

[6]This data is at the ELI-level and part of the supplementary material for the published version of NS downloaded via their website.

collecting data on about 130.000 products per month from around 27.000 retails outlets across 87 geographical areas in the United States. The non-shelter components of the CPI represents about 70% of consumer expenditure.

In order to match markup data at the NAICS level with price moments at the ELI level, we construct a crosswalk between the different classifications by hand. In particular, we build many-to-many matches between 6-digit NAICS and ELI categories. The match is made by hand according to a comparison of the description of the product descriptions (as well as individual item names contained in in the CPI-RDB).

4.2 Calibration

We calibrate three sets of parameters. The first set of parameters are the elasticity of substitution in K sectors $\{\{\theta_{k,t}\}_{t=1980}^{2016}\}_{k=1}^{K}$, where $\theta_{k,t}$ is set according to $\theta_{k,t} = \mu_{k,t}/(\mu_{k,t} - 1)$. Here, $\mu_{k,t}$ is the estimate of smoothed markup in sector k at year t described in section 2.1. In the following sections, we will consider three cases: $K = 1$, $K = 8$ and $K = 20$.

Externally Calibrated Parameters The second sets of parameters are calibrated using conventional values in the literature. The model is calibrated at a monthly frequency with $\beta = 0.96^{1/12}$. I set κ such that labor supply in the flexible price steady state is 1/3. I calibrate $\mu = 0.0018$ to match the mean growth of nominal GDP minus real GDP during the period 1998-2005.[7] Following Nakamura and Steinsson (2010), I choose the persistence of idiosyncratic shock ρ_z to be 0.7. These parameters are shown in Table 1

Table 1: Externally Calibrated Parameters

Parameter	Description	Value
β	Discount factor	$0.96^{1/12}$
κ	Labor coefficient	2.25
μ	Mean growth rate of S_t	0.0018
σ_S	Standard deviation growth rate of S_t	0.0032
ρ_z	Idiosyncratic productivity persistence	0.7

Internally Calibrated Parameters We next calibrate our model to match the micro pricing moments documented in section 2.1. These parameters govern the cross sectional

[7] The moments of price adjustment for calibration in Nakamura and Steinsson (2010) is calculated using data from 1998 to 2005.

behavior of price changes. For sector k, there are four remaining parameters: the standard deviation of idiosyncratic productivity shocks σ^z, the probability of idiosyncratic productivity shocks ξ, the probability of zero menu cost ϕ and the magnitude of menu cost f. I calibrate these four parameters to match the following moments: the median frequency, the 25 percentile of the absolute size distribution, the median absolute size and the 75 percentile of the absolute size distribution. Table 2 presents the calibrated parameters across sectors for the one-sector and eight-sector model.

Table 2: Internally Calibrated Parameters

Sector	Markup	σ^z	ξ	ϕ	f
One-sector model	1.36	0.081	0.064	0.035	0.067
Eight-sector model					
Agriculture	1.47	0.270	0.136	0.035	0.022
Mining and Utilities	1.21	0.144	0.104	0.069	0.007
Manufacturing	1.48	0.122	0.084	0.033	0.035
Retail and Wholesale	1.12	0.028	0.184	0.021	0.064
Services (information, finance)	1.85	0.056	0.086	0.055	0.037
Education and Health Care	1.14	0.042	0.213	0.015	0.082
Services (entertainment etc.)	1.24	0.048	0.142	0.027	0.057
Other Services	1.27	0.039	0.229	0.011	0.102

Model Fit The model fits both the pricing moments targeted and pricing moments not targeted really well. This is not surprising because the advantage of the second-generation menu cost models is the ability to match the empirical distribution of price changes. Table 3 shows the model fit for the one-sector model.

Table 3: Model Fit (one-sector model)

Moment	Data	Model
Moments targeted		
Frequency	0.06	0.05
Absolute size (median)	0..06	0.06
25th percentile size	0.03	0.03
75 percentile size	0.12	0.11
Moments not targeted		
Fraction of price increase	0.68	0.75
Size of price increase	0.07	0.07
Size of price decrease	0.09	0.09

5. Results

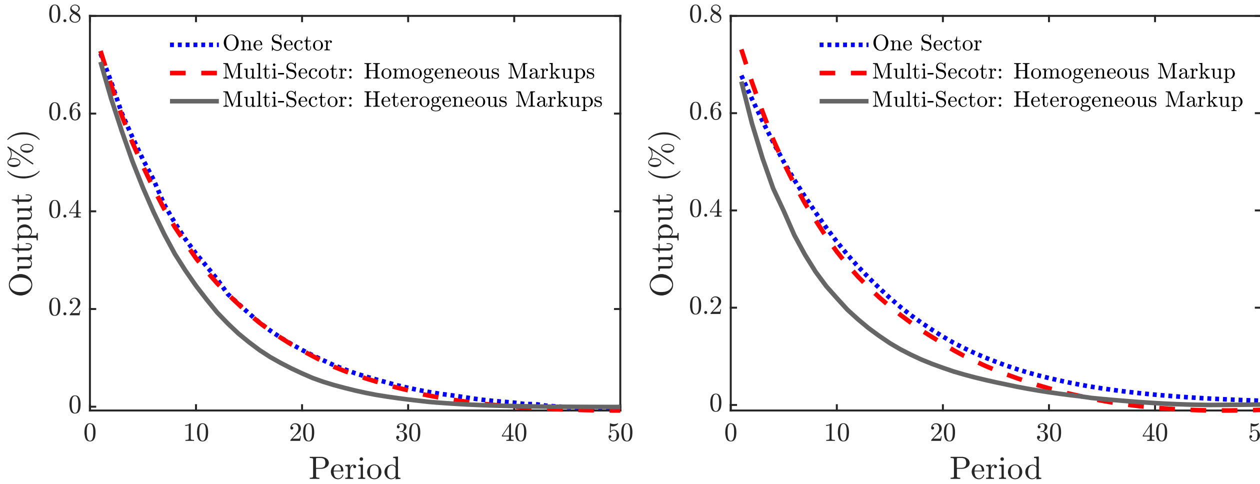
5.1 Heterogeneous Markups and Monetary Non-neutrality

We shock the economy with a one-time monetary shock and investigate how introducing heterogeneous sectoral markups affect monetary non-neutrality. Formally, we feed in a one-time unexpected monetary shock at $t = 1$ that dies out from $t = 2$ onwards. That is, $\epsilon_1^S = \bar{\epsilon}$ and $\epsilon_t^S = 0 \; \forall t > 1$. The impulse response functions (IRFs) are then computed by imposing the perfect foresight assumption. The size of the shock $\bar{\epsilon}$ is normalized to increase the nominal spending by 1%.

Figure 2 plots the IRFs of real output to a monetary shock in various models. The solid black lines (dashed red lines) depict the results in a multi-sector model with heterogeneous (homogeneous) steady-state markups. The dotted blue lines represent the results in a one-sector model. We consider an Eight-sector version (panel a) and a Twenty-sector version (panel b) of multi-sector models.

Monetary non-neutrality is reduced in a multi-sector model with heterogenous steady-state markups (solid black lines) as compared to a one sector model (blue lines). To provide a quantitative number, the cumulative output response in the Eight-sector model with heterogenous steady-state markups is 30.6 percent lower compared to the one-sector model. Note that the multi-sector model with heterogenous steady-state markups differ

Figure 2: Heterogeneous Markups and Monetary Non-neutrality



(a) Eight-sector Model

(b) Twenty-sector Model

Note: This figure plots the IRFs of real output to a monetary shock in various models. The solid black lines (dashed red lines) depict the results in a multi-sector model with heterogeneous (homogeneous) steady-state markups. The dotted blue lines represent the results in a one-sector model. We consider an Eight-sector version (panel a) and a Twenty-sector version (panel b) of multi-sector models.

from the benchmark one-sector model in many dimensions. Particularly, the multi-sector model features other sources of heterogeneities: productivity distribution and frequency of price adjustments.

We conduct a semi-decomposition exercise to decompose the total reduction in monetary non-neutrality into the component that arises from the introduction of heterogenous markups and the component due to other multi-sector features. To do so, we recalibrate a multi-sector model that share the same features and target to the same moments except that steady-state markups are imposed to be homogenous across sectors. These IRFs are plotted in dashed red lines. Comparing the two versions Eight-sector models, the cumulative output response in the baseline model with heterogenous market power is reduced by 23.3 percent. In contrast, the cumulative output response in the Eight-sector model with homogeneous market powers is merely 9.6 percent lower than that of the one-sector model.

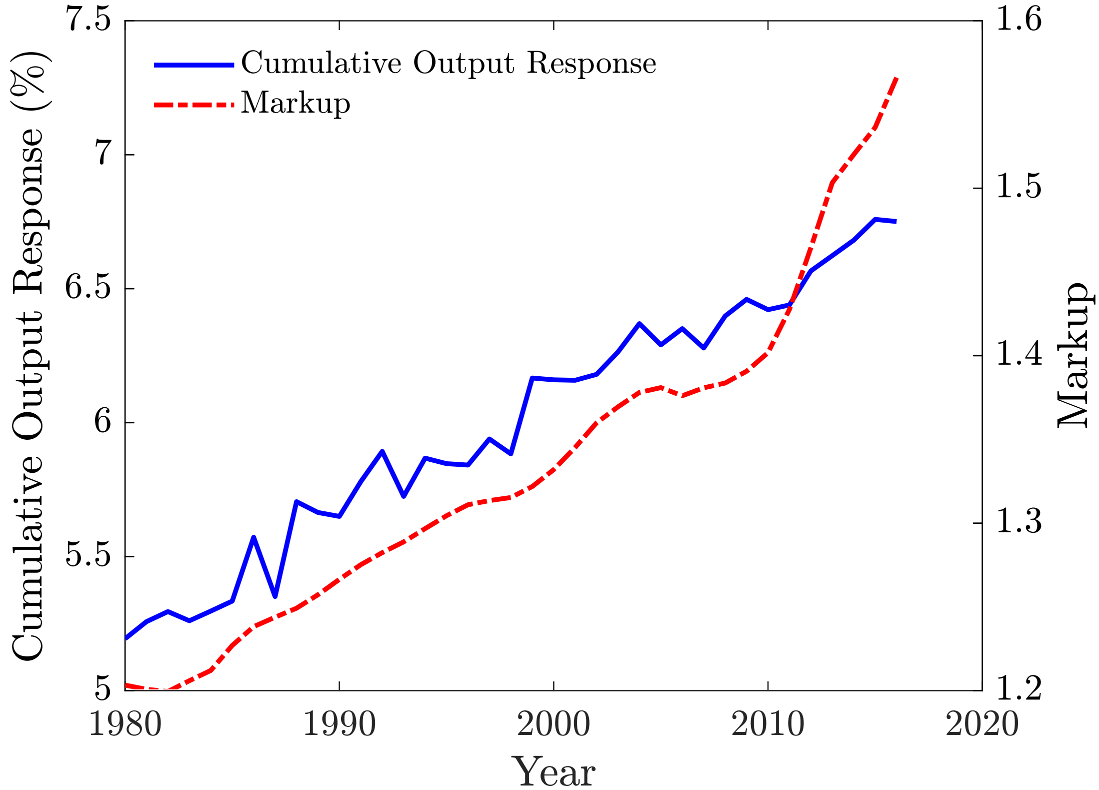
Similarly, in the cumulative output response in the Twenty-sector model with heterogenous steady-state markups is 31% lower compared to the one-sector model and 23% lower compared to the with homogeneous steady-state markups. Hence, heterogenous steady-state markup reduces monetary non-neutrality.

5.2 The Rise of Markups and Monetary Non-neutrality Over Time

Markups have changed substantially over time as it is documented in Figure 1. The economy-wide moving average markup, which is the sector-size weighted average of moving average markups at industry level, has increased substantially: see the red dashed line in Figure 3. We now assess how the rise of markups in the data affect the monetary non-neutrality in the model. To this end, we calibrate the model for each year from 1980 to 2016. In each calibration, we change one set of parameters: the elasticities of substitution to match the changing moving average markups. The monetary non-neutrality is computed for each year.

Figure 3 plots the evolution of the aggregate makeup in the U.S. (dashed red line) and the implied evolution of the aggregate monetary non-neutrality (solid blue line). Interestingly, the aggregate monetary non-neutrality tracks the the evolution of aggregate markups closely. Zooming to the sectoral level shows that similarly patterns hold true in each of the eight sectors considered in our calibration, see Figure 8. The discussions about the economic mechanism is postponed to Section 6. An important message for central bankers is that monitoring the evolution of aggregate markup is important for determining the right amount to nominal demand policy. According to our model, the elasticity of monetary non-neutrality with respect to markup, defined as $\frac{\partial log(\text{monetary non-neutrality})}{\partial log(\text{markup})}$, is 1.09.

Figure 3: Aggregate Cumulative Output Response Over Time (eight sectors)

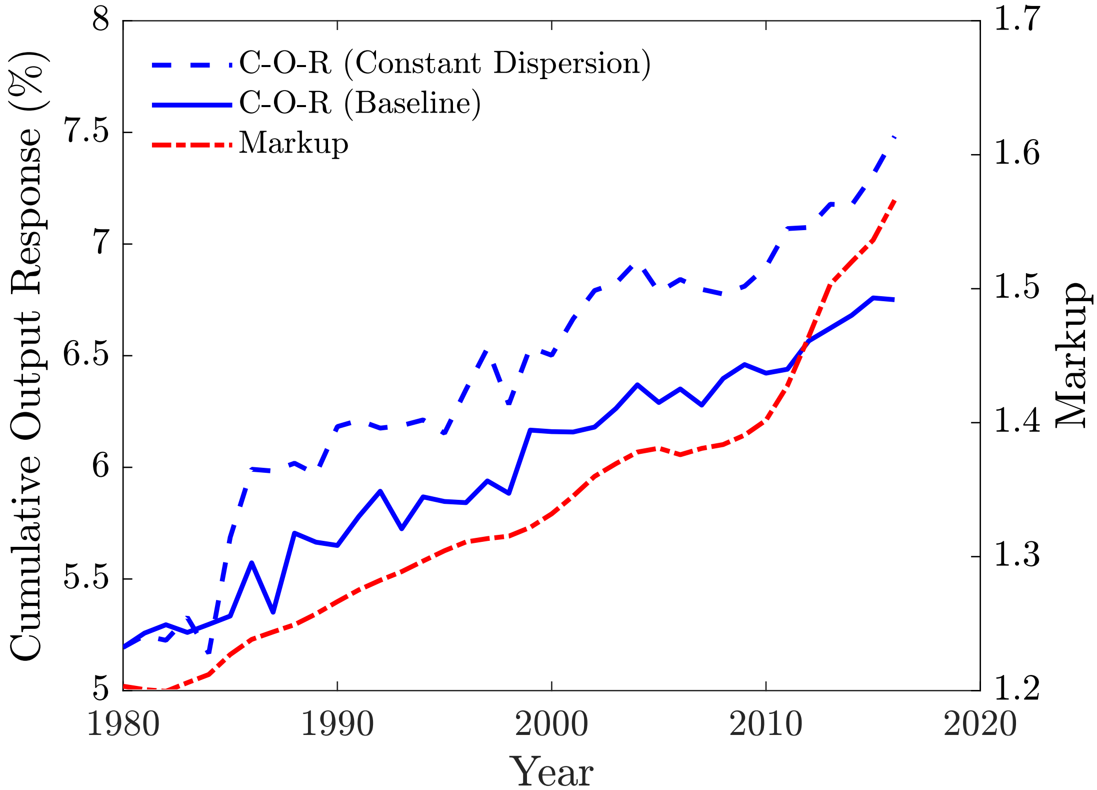


Note: This figure plots the evolution of the aggregate makeup in the U.S. (dashed red line) and the implied evolution of the aggregate monetary non-neutrality (solid blue line).

5.3 The Role of Sectoral Markup Dispersion

The second observation documented in Figure 1 is that the moving average markups have became more dispersed across sectors. The evolution of the aggregate monetary non-neutrality computed in the previous Subsection 5.2 incorporates both the increases in the aggregate markup and the increase in the dispersion. How does the trend in moving average markups' dispersion affect the aggregate monetary non-neutrality? The following experiment addresses this question.

Figure 4: Aggregate Cumulative Output Response Over Time (Constant Dispersion)



Note: The blue dashed line plots the implied evolution of the aggregate monetary non-neutrality in our baseline calibration. The blue solid line plots the implied evolution of the aggregate monetary non-neutrality for the counterfactual where the the aggregate markup is the same as the baseline but the dispersion of markups over time is fixed at the level of 1980. We achieve this by equalizing the annual markup increments across eight sectors. The red dash-dotted line shows the evolution of the aggregate makeup in the U.S.

We consider a counterfactual scenario, where the dispersion of markups is fixed at the level of year 1980 whereas the aggregate markup increases as it is indicated by the dashed red line in Figure 4. The model is re-calibrated for each year, based on the counterfactual evolution of sectoral markups. The solid blue line in Figure 4 plots the implied monetary non-neutrality in the counterfactual scenario. For comparison, the monetary non-neutrality according to the actual evolution of markups are plotted in the same figure using the dash blue line.

The monetary non-neutrality measured by the cumulative output response is 44% higher in 2016 than that of 1980. This increase is about 150% the size as it is implied by the actual changes in the moving average markups. The annual growth rate (linear trend) of the monetary non-neutrality according to the actual evolution of markups is 0.7%, while in the counterfactual it is 0.9%. The elasticity of monetary non-neutrality with respect to markup is 1.5 in this counterfactual analysis.

5.4 Projections of Monetary Non-neutrality

The observed trend in markup has lasted for three decades and is likely to persist. What would happen to monetary non-neutrality in the future? The following exercise addresses this question. To this end, we first forecast the smoothed sectoral markups and sector sizes using a simple model with a linear trend and a constant term. Figure 12 reports the projected evolution of smoothed markups by sectors at one-digit level and their dispersions. Those projected smoothed markups are then used as inputs to the model to compute the monetary non-neutrality in the future.

Table (4) reports the main findings. By the 2030s the smoothed aggregate markup is expected to reach to 1.76, which corresponds to an aggregate monetary non-neutrality of 6.9%. The markup elasticity of monetary non-neutrality is projected to be equal to 0.67 in the 2030s. Note that the markup elasticity of monetary non-neutrality is declining over time, due to the rise in the market power. We discuss the mechanism behind this result in Section 6.

Decade	Smoothed Aggregate Markup	M-N	Markup Elasticity of M-N
1980-2020	1.36	5.8%	1
2020s	1.65	6.5%	0.71
2030s	1.76	6.9%	0.67

Table 4: Monetary Non-neutrality in the Past and Future

6. Inspecting the Mechanism

How does monetary non-neutrality varies with market competitiveness or firms' desired markups? In this section, we first show that, keeping everything else equal, monetary non-neutrality is an increasing and concave function of firms' optimal markups.

6.1 Monotonicity and Concavity

To do this, we introduce a systematic monetary policy shock into our calibrated one-sector model in the previous section. Specifically, we calibrate $\mu = 0.0018$ to match the mean growth of nominal GDP minus real GDP, and $\sigma_S = 0.0032$ to match the standard deviation of nominal GDP growth rate during the period 1998-2005. We solve the model numerically using the method proposed by Krusell and Smith (1998).[8]

We then vary the desired markups in the economy and solve for the equilibrium with different markups. We finally plot the variance of log output under each equilibrium.[9] As shown in figure 5, monetary non-neutrality, measured by the variance of log output, is an increasing and concave function of firms' optimal markups: The markup elasticity of monetary non-neutrality is decreasing in the initial level of desired markup. The higher the initial desired markup is, the greater the monetary non-neutrality increases.

We can now revisit our quantitative results through the lens of this monotonic and concave relationship. The monotonicity explains the results in section 5.2. The concavity, combined with the fact that the increase in markup dispersion is mostly driven by the right tail, explains our results in section 5.3. In the remaining part of this section, we therefore inspect the key mechanism behind this increasing and concave relationship.

6.2 The Mechanism

To understand the mechanism behind the monotonicity and concavity, we follow the framework proposed by Caballero and Engel (2007). Specifically, we decompose the change of the aggregate log price after a shock to aggregate log nominal spending shock Δs to the following two components:

$$\lim_{\Delta s \to 0} \frac{\Delta p}{\Delta s} = \underbrace{\int \Lambda(x) f(x) dx}_{\text{Intensive Margin =Freq}} + \underbrace{\int x \Lambda'(x) f(x) dx}_{\text{Extensive Margin}}, \tag{17}$$

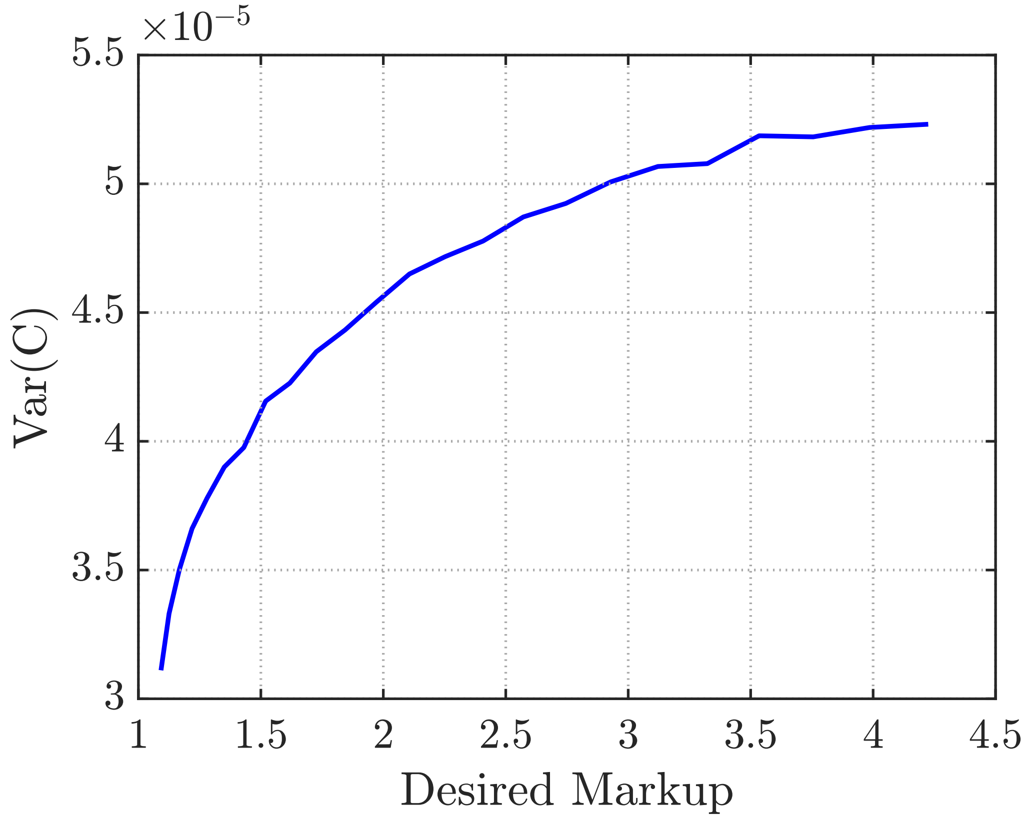
where $f(x)$ is the distribution of price gaps, $\Lambda(x)$ is the adjustment probability which is increasing in the price gap x.

The intensive margin reflects the inflation contribution of those firms which would have adjusted their prices even without the monetary shock. It is equal to the frequency

[8] Similar methods have been used in the class of menu cost models, for example, by Nakamura and Steinsson (2010), Midrigan (2011) and Vavra (2014).

[9] As argued by Nakamura and Steinsson (2010), the variance of log output is a good measure of monetary non-neutrality. proportional to IRF

Figure 5: Markups and Monetary Non-neutrality

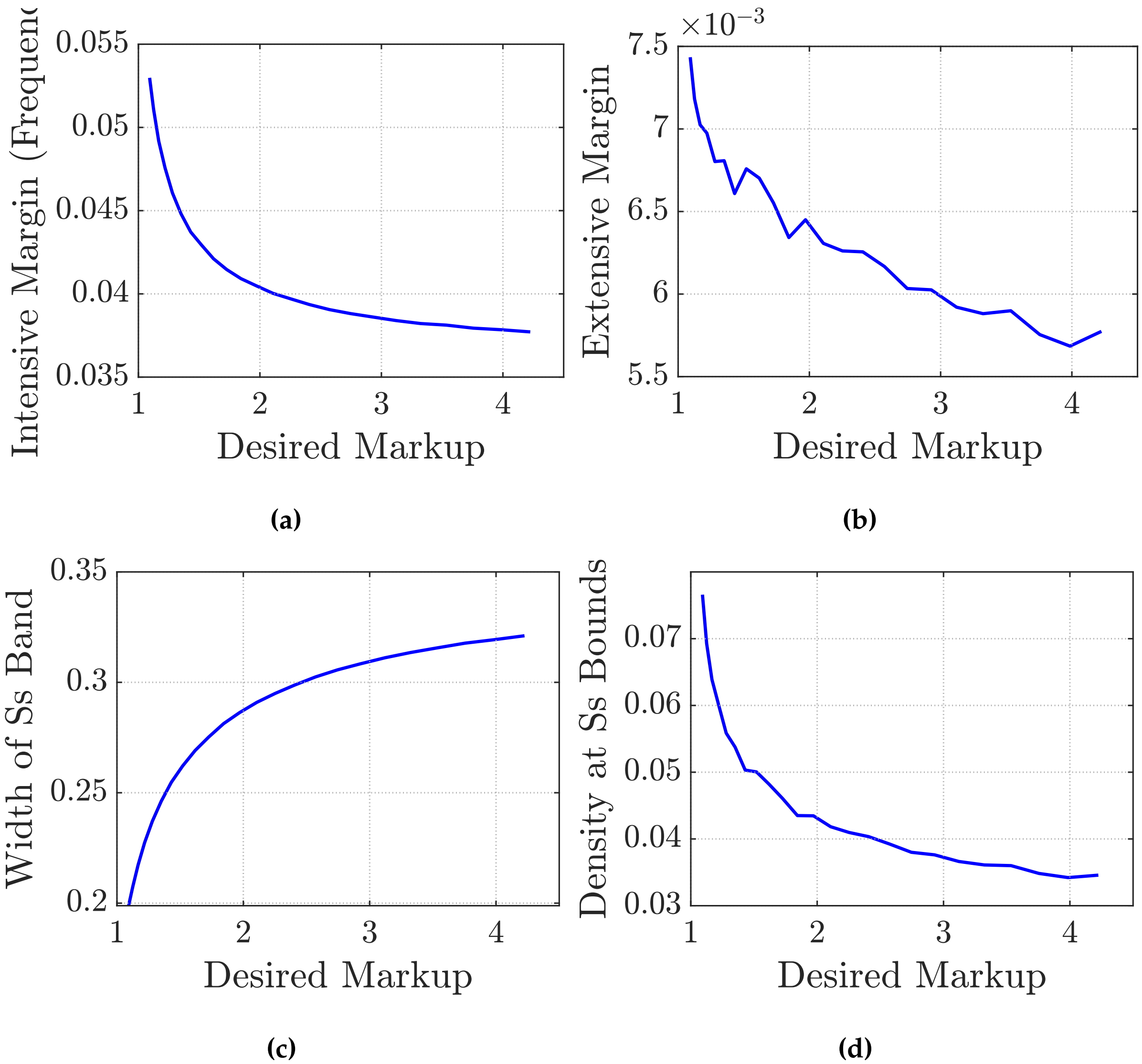


of price changes in the economy. The extensive margin gives the inflation contribution due to variation in the composition of adjusters in response to the monetary shock. The magnitude of the extensive margin is again determined by two terms: (i) the density of firms at the margin of adjustment $\Lambda'(x)$, (ii) the size of price adjustment $|x|$.

Figure 6 plots how these margins vary with the desired markup in the calibrated one-sector model. Panel (a) shows that the intensive margin (frequency) is a decreasing and convex function of the desired markup. This is because as the market becomes less competitive, firms are less likely to adjust their prices, since the profit loss of deviating from optimal prices is small. This intuition is also confirmed in Panel (c), which shows that the average width of the inaction band is increasing with the optimal markup. Panel (b) shows that the extensive margin is also a decreasing and convex function of the desired markup. This is driven by the fact that the average density at the inaction bounds is a decreasing and convex function of the desired markup, as shown in panel (d). This convexity of the intensive and extensive margin is a reflection of the leptokurtic shape of the price gap distribution in the class of second-generation menu cost models.

Considering the following relationship: $\lim_{\Delta s \to 0} \frac{\Delta y}{\Delta s} = 1 - \frac{\Delta p}{\Delta s}$, it is therefore straight forward to show that monetary non-neutrality is an increasing and concave function of the desired markup, as shown in Figure 5.

Figure 6: The Intensive and Extensive Margin



7. Conclusion

The heterogeneous increases in firms' market power that are observed in the data have important implications for monetary non-neutrality. A quantitative multi-sector menu cost model with heterogenous market competition predicts the markup elasticity of monetary non-neutrality of 1. The increased dispersion in markups across sectors observed in the data contributes negatively to the elasticity. If the increase in markup had been equally distributed across sectors, the markup elasticity of monetary non-neutrality would be equal to 1.6.

Our paper provides a toolbox that assists central bankers in keeping track of monetary non-neutrality. Our calculation of the markup elasticity of monetary non-neutrality can inform central banks to determine the correct amount of nominal demand stimulus package in the current and future economy with rising markups.

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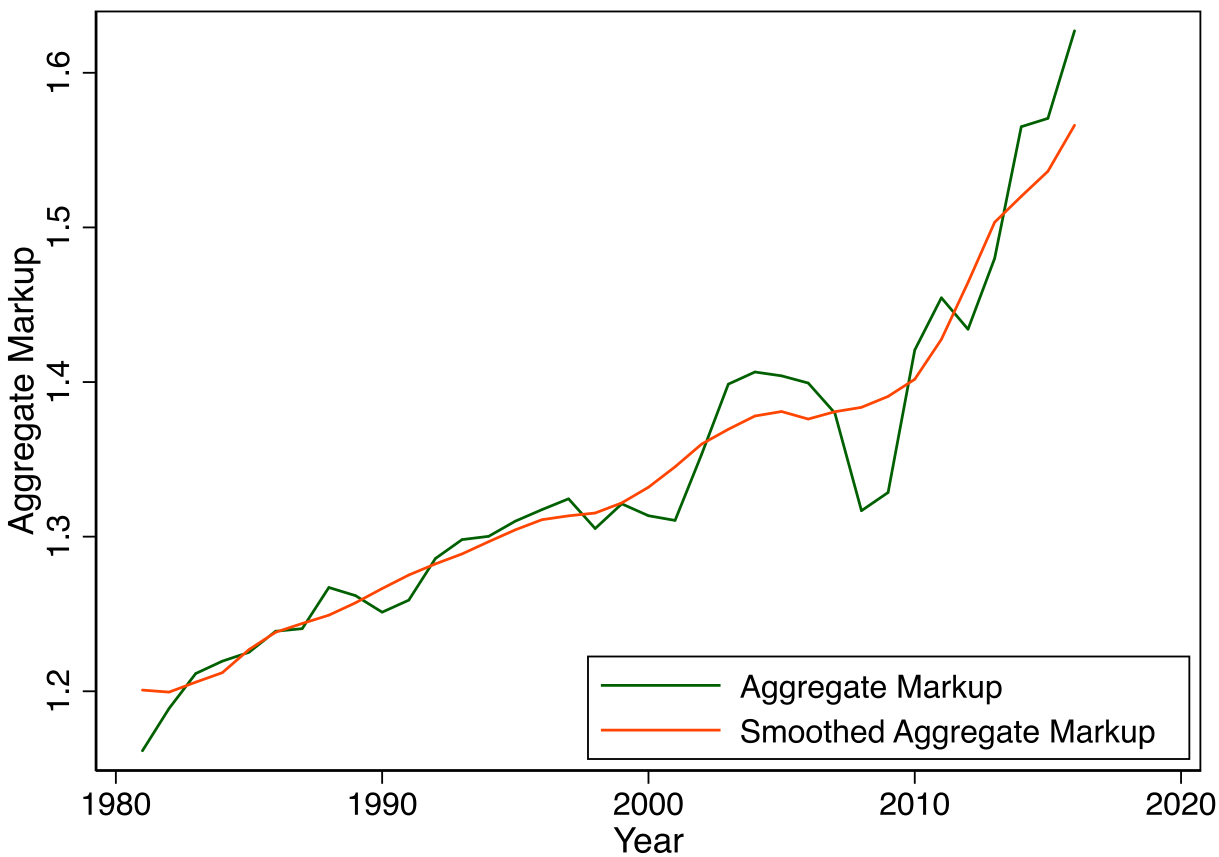
A. Tables and Figures

Figure 7: The evolution of the Aggregate Markup in the U.S



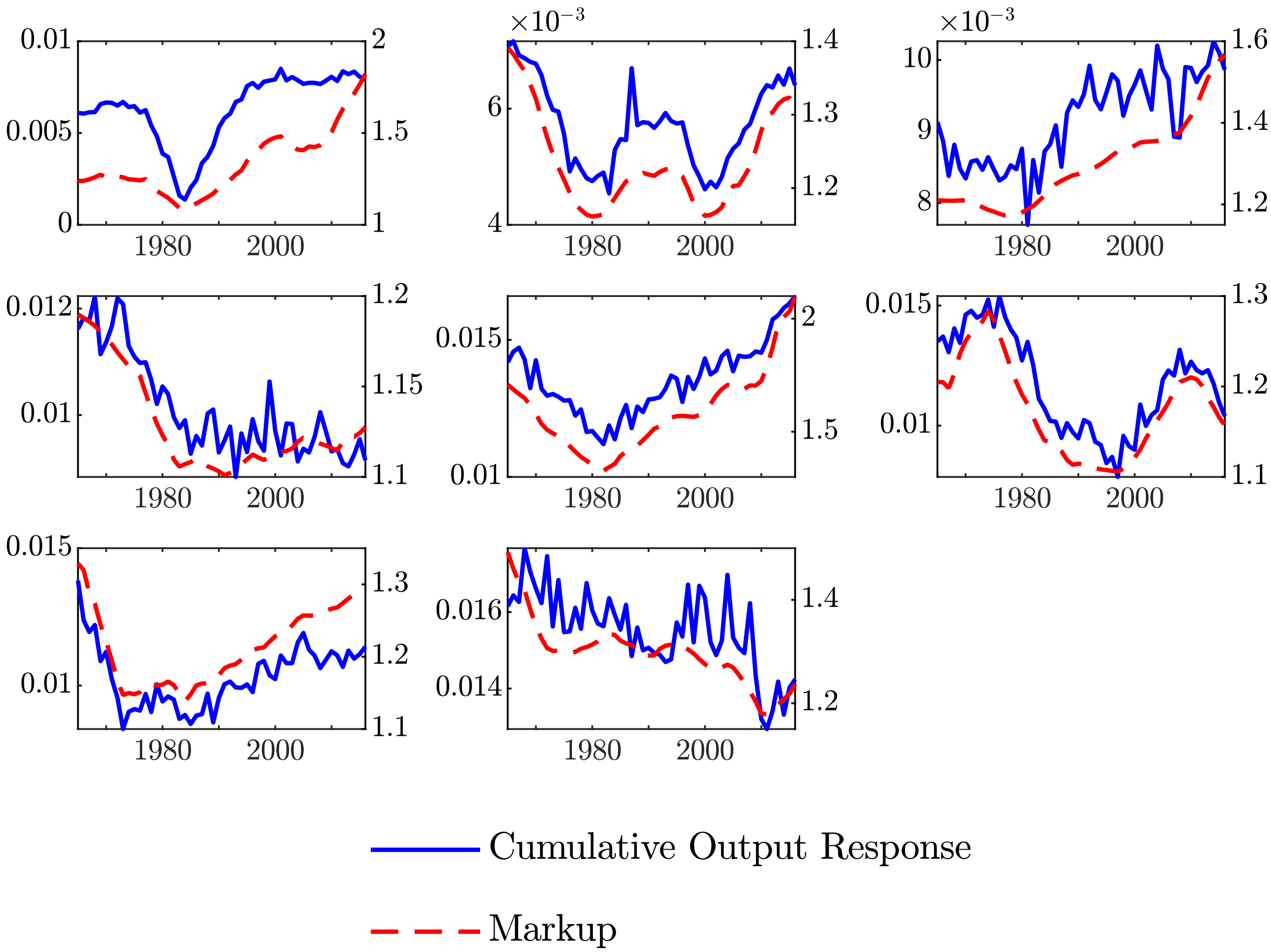
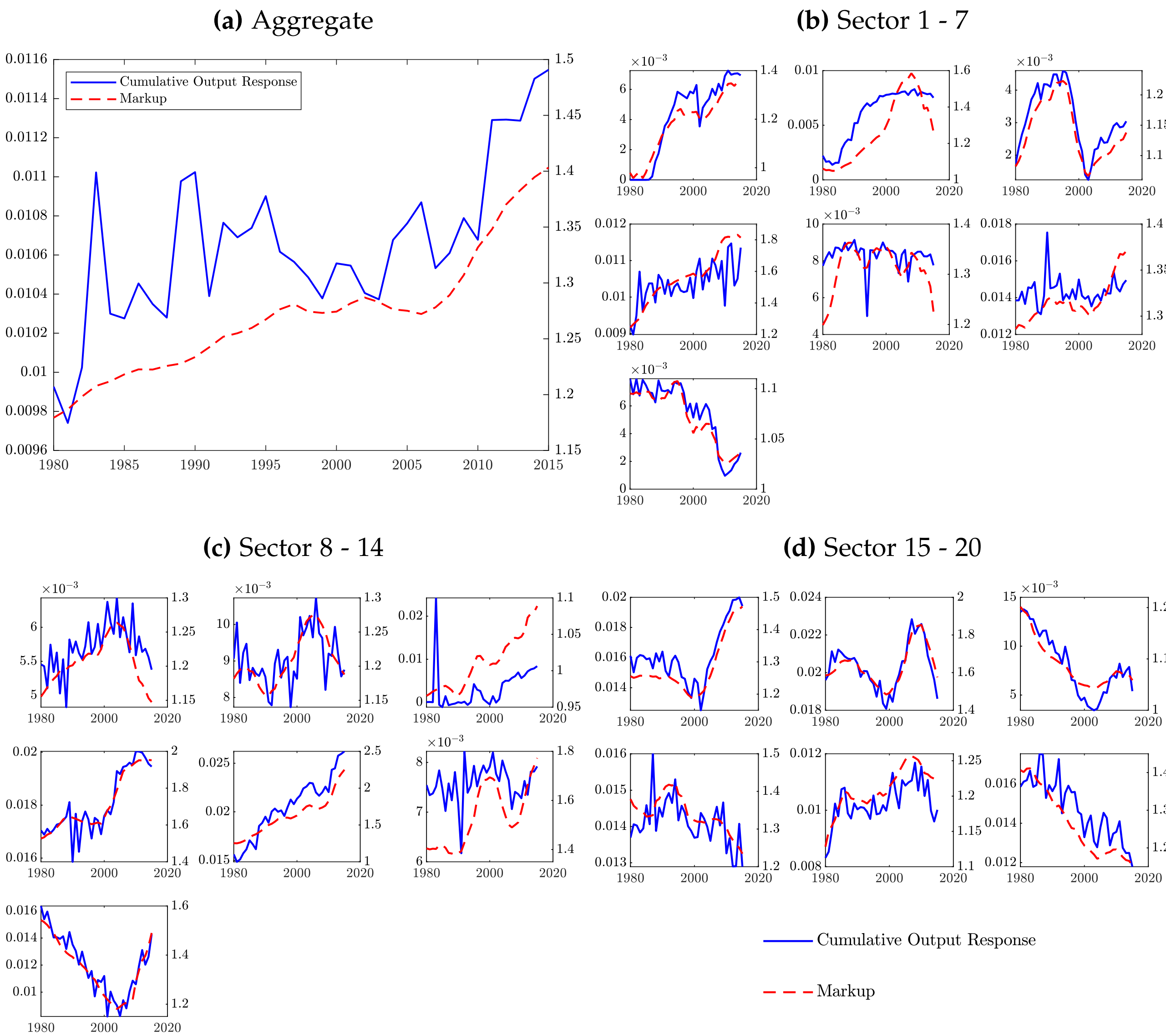


Figure 8: This figure plots the evolution of the sectoral makeup in the U.S. (dashed red line) and the implied evolution of the sectoral monetary non-neutrality (solid blue line).

Figure 9: Cumulative Output Response Over Time (twenty sectors)



Note:

Figure 10: Sectoral Cumulative Output Response Over Time (Constant Dispersion)

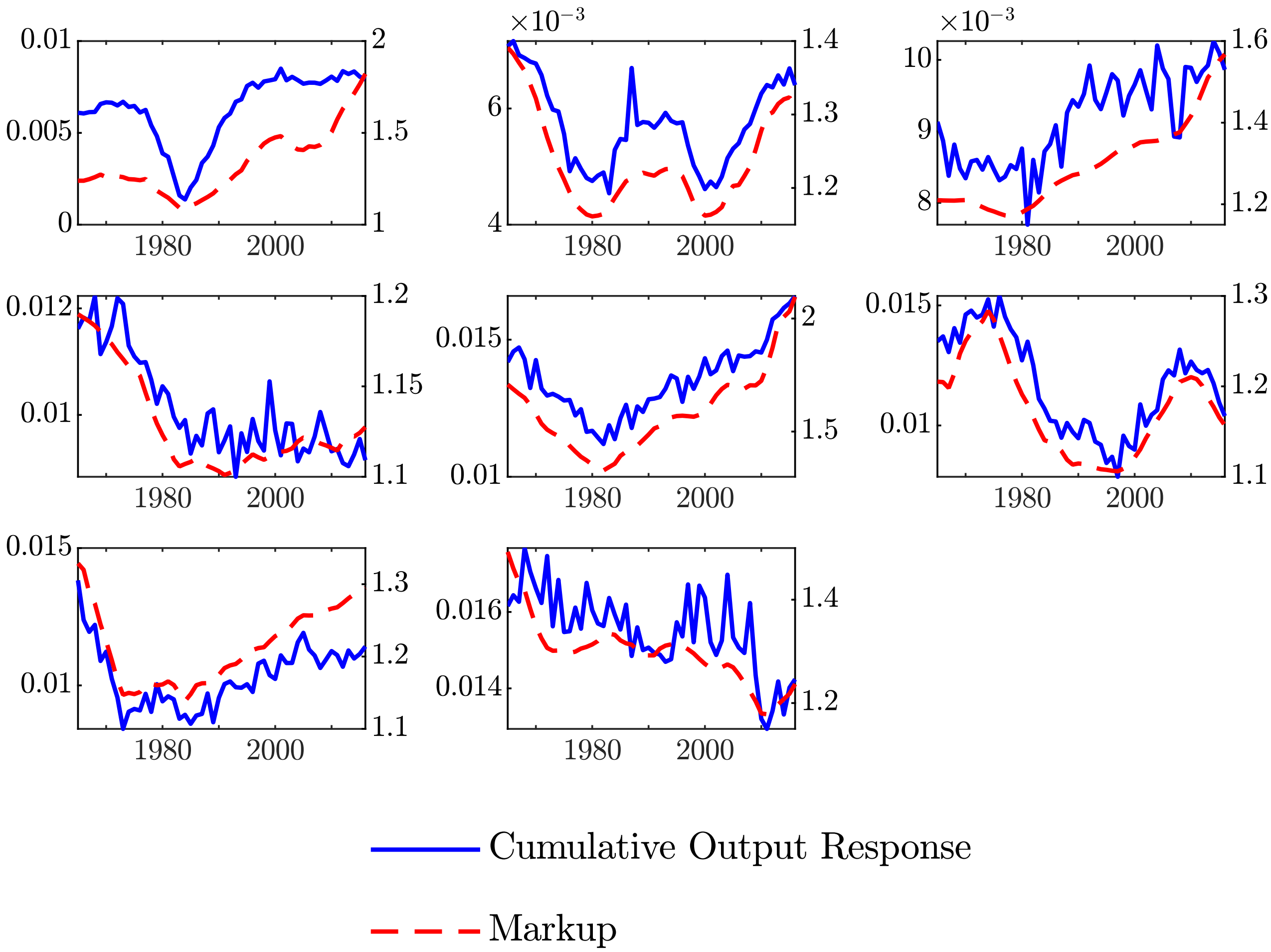
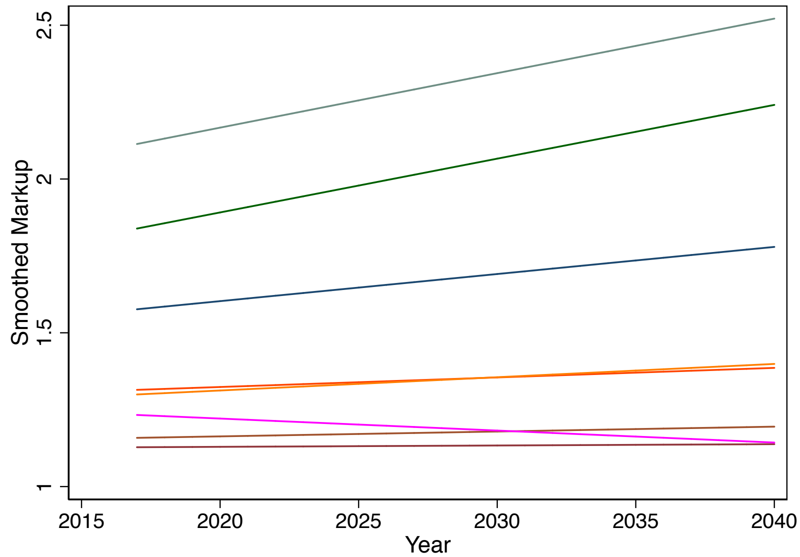
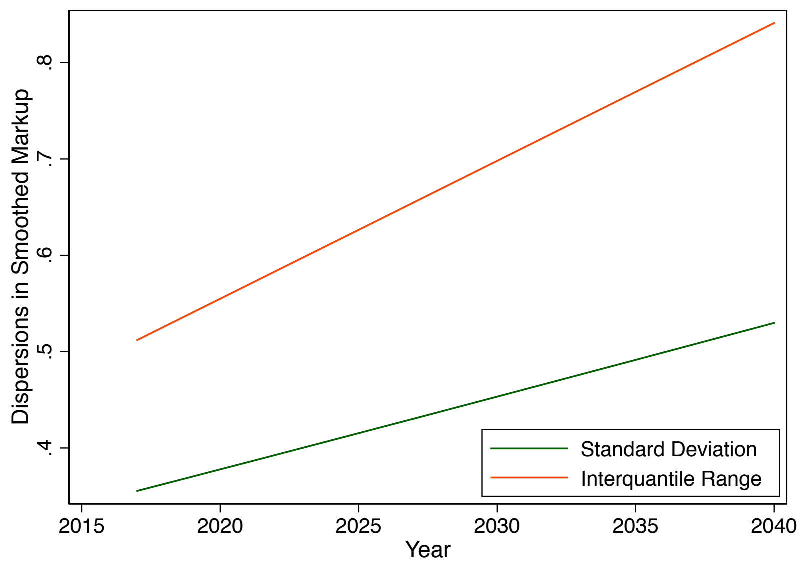


Figure 11: This figure plots the evolution of the sectoral makeup in the U.S. had the markups increased equally across sectors (dashed red line) and the implied evolution of the sectoral monetary non-neutrality (solid blue line).



(a) Smoothed Markups by Sectors



(b) Cross-sectors Dispersion of smoothed Markup

Figure 12: Authors' own calculation. This figures plots the forecasts of the smoothed markups and their cross-sector dispersion.