Evaluating effectiveness of price level targeting in the presence of increasing uncertainty

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Abstract

We argue that understanding the macroeconomic effects of increasing economic uncertainty requires understanding nominal rigidities. In the standard new Keynesian model where all firms face the same degree of nominal rigidity, heightened uncertainty leads to higher inflation and lower output. Introducing heterogeneity in price stickiness, suggested by micro-evidence on prices, changes this prediction of the model. In the new model, increased uncertainty leads to decrease in both inflation and output. These effects are more pronounced with higher trend inflation. We find that price-level targeting is more effective in dealing with the consequences of increasing uncertainty than inflation targeting.

Keywords: Uncertainty Shocks; Inflation; Trend Inflation; Multi-Calvo; New Keynesian.

JEL Classification Numbers: E52, E58.

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1 Introduction

What are the effects of increasing uncertainty on the macroeconomy? How can central banks deal with it? This paper aims to provide answers to these questions. To this end, we use New Keynesian (NK) Dynamic Stochastic General Equilibrium models as a laboratory. Specifically, we consider two versions of the model. The first is the standard NK model, where all firms face the same degree of nominal rigidities. The second is a multi-sector NK model that accounts for the heterogeneity in price stickiness we observe in the micro-data, namely a Multiple Calvo (MC) model.[1] Moreover, we allow for positive trend inflation, as suggested by Ascari and Ropele (2007) and Ascari and Sbordone (2014). These studies successfully argue that monetary transmission mechanism should be studied by using a model with positive trend inflation. We also consider two alternative policy rules. The first rule is an empirically relevant Taylor-style rule under which the short-term interest rate reacts to changes in inflation, whereas the other is a price level targeting rule under which the short-term rate responds to changes in the price level. The latter rule is similar to the one recently adopted by the Fed.

We first consider the case with inflation targeting policy. We find that in the standard model, while output falls with increasing uncertainty, inflation increases.

[1] Kara (2015) replaces Calvo pricing in the SW model with MC pricing and estimates the resulting SW-MC model with Bayesian techniques using US data. He shows that while the SW-MC model fits the macroeconomic data as well as the SW model, two disturbing problems of the SW model disappear when heterogeneity in price stickiness is introduced. First, the MC model does not require as large mark-up shocks as the SW model, addressing the critique by Chari, Kehoe and McGrattan (2009). Second, the MC matches the data on reset price inflation better the SW model, providing an explanation put forward by Bils, Klenow and Malin (2012. The model is recently employed to evaluate recent policy proposal to increase the inflalation target to 4% see (Kara and Yates (forthcoming).

The predictions of the MC model are different from those of the standard model without heterogeneity. In the MC model, both inflation and output fall in response to an increase in uncertainty. We further find that trend inflation also plays an important role in that it significantly amplifies the recessionary effect of increasing uncertainty.

As noted in Fernandez-Villaverde et al. (2015), a key to understanding the effects of uncertainty shocks in NK models is to understand the asymmetry in firms' profit functions. This asymmetry implies that profits are lower when a firm's price is lower relative to her competitors. When prices are sticky, this feature of the model has an important implication for firm's pricing behaviour. With sticky prices, since an increase in uncertainty increases the probability that a firm's relative price may be lower in future, firms resetting their prices allow for precautionary markups to avoid future states with lower relative price. As a result, the size of the desired markup increases, leading firms to bias their prices upwards. In addition to this channel, another channel through which increased uncertainty affects firms' pricing behaviour is the aggregate demand channel. An increase in uncertainty causes contraction in aggregate demand, putting a downward pressure on prices. However, it appears that the precautionary markup channel is dominant in the standard new Keynesian model, bringing about an increase in inflation following an uncertainty shock.

We argue that the standard model can only capture a part of the big picture since the model lacks heterogeneity in firms' pricing behaviour. Specifically, the model cannot account for the fact that sectors may respond differently to increasing uncertainty. The MC model is characterised by sectors with varying degree of price stickiness. In this model, the size of precautionary markups depends crucially on the degree of price stickiness. Therefore, the presence of heterogeneity in nominal rigidities in the MC gives rise to a distribution of precautionary markups. This distribution in precautionary markups results in different sectoral inflation responses. Sectors with sticky prices require large precautionary markups and, therefore, inflation increases in such sectors. On the other hand, sectors with relatively flexible prices do not require large precautionary markups and, consequently, inflation fall in these sectors .

In the MC, on impact of the shock, firms in sectors with lower price stickiness dominate the initial part of the price adjustment process[2]. This is because, with a lower degree of nominal rigidity, such sectors are more responsive to shocks than the sluggish sticky-price sectors. As a consequence, aggregate inflation falls on impact. In the latter part of the price adjustment process, since flexible price sectors have already adjusted their prices, the sticky-price sectors start to influence the price adjustment process. Since inflation is positive in these sectors, aggregate inflation starts to recover and overshoots its steady-state value. After some time of the shock, the effect of the shock on inflation fades away and inflation returns to its steady-state value.

Higher trend inflation exacerbates the recessionary effect of increasing uncertainty. This is because with higher trend inflation, firms allow for even larger price mark-ups.

Finally, our results suggest that the disruptive effect of uncertainty shocks are

[2]This feature of the MC is emphasised in Carvalho and Schwartzman (2015) and Kara (2015)

much smaller under price-level targeting than inflation targeting. As noted above, the disruptive effect of uncertainty shocks arise due to the fact that such shocks increase the uncertainty about relatives prices. Price-level targeting helps to reduce such uncertainty, as the central bank sets monetary policy to keep prices stable. This policy stance makes the evolution of prices more certain and, therefore, reduces the need for precautionary markups and the effect of uncertainty on firms' pricing behaviour. Reduced uncertainty about prices also lowers the uncertainty on interest rates and, as a result, households' precautionary savings motives.

The rest of this paper is organised as follows. Section 2 briefly reviews the literature closely related to our paper. Section 3 outlines our model. Section 4 discusses the micro-evidence on prices and uses it to calibrate the model in this paper. Section 5 explains the transmission mechanism in both the standard and the MC model through which uncertainty shocks affect inflation. We also discuss, in section 6, how the results in section 5 change when we replace Calvo pricing assumption with Rotemberg pricing. Finally, section 7 concludes the paper.

2 Relation to the existing literature

Our paper belongs to the growing literature that aims to understand how uncertainty affects real economy. Bloom (2009) shows that second-moment uncertainty shocks play a quantitatively important role in driving business cycle fluctuations in the US economy. Since the publication of Bloom's paper, there has been increased interest in exploring how the effect of uncertainty propagates through the economy and which propagation mechanisms are important for reconciling theory with evidence. Bloom (2009) finds firms' "wait-and-see" motive to play an important role in explaining how uncertainty affects the US economy. In contrast, Bachmann and Bayer (2013) use German firm-level data to calibrate the heterogeneous-firm DSGE model to show that "wait-and-see" is not a major source of business cycle fluctuations in Germany. Bloom (2014) notes, "that this literature provides suggestive but not conclusive evidence that uncertainty damages short-run growth." In a more recent paper, Bloom et al. (2018) argue in favour of modelling both first and second-moment shocks together in order to explain observed business cycle fluctuations. Cascaldi-Garcia and Galvao (forthcoming) show that, since uncertainty and news shock are correlated, disentangling the two results in uncertainty shocks having bigger effects than otherwise.

The new Keynesian literature has also explored different channels through which uncertainty shocks affect the economy. Born and Pfeifer (2014) use a NK model with both price and wage rigidities and find uncertainty shocks to have little effect on macro variables. Fernandez-Villaverde et al. (2015) use a similar framework but find bigger effects when the economy is at the zero lower bound. However, both Born and Pfeifer (2014) and Fernandez-Villaverde et al. (2015) find inflation to increase in response to an uncertainty shock. Fernandez-Villaverde et al. (2015) show that, assuming that the monetary policy responds to an increase in uncertainty by increasing interest rates, inflation decreases in response to an increase in uncertainty. The analysis in Fernandez-Villaverde et al. is predicated on the assumption that rational firms would anticipate that the central bank would respond to an increase in uncertainty to keep inflation closer to the target. This anticipation decreases the incentive for firms to bias their prices upwards. As a result, instead of increasing prices, price setting firms decrease their prices in response to contraction in aggregate demand. Fernandez-Villaverde et al. only provide suggestive evidence from the minutes of the FOMC to support their assumption. The model in Mumtaz and Zanetti (2013) is also able to replicate the behaviour of inflation. However, this is due to a very low value for Frisch elasticity of labour supply assumed in their paper. This may be problematic as the model with low value for Frish elasticity of labour supply can no longer explain observed volatility in labour hours.

An alternative modelling approach relies on incorporating additional demand channels into the standard NK framework. Basu and Bundick (2017) reformulate the standard NK model to allow for recursive preferences, as in Epstein and Zin (1989). The mechanism at work results in increased risk aversion, resulting in a larger contraction in aggregate demand. This contraction is sufficiently large that it leads to a fall in inflation. However, Bekaert et al. (2013) show that the risk aversion component of VIX (proxy for uncertainty used in Basu and Bundick) does not have a strong effect on the business cycle. Leduc and Liu (2016) study the effects of uncertainty shocks by using a NK model with search and matching frictions. An increase in uncertainty increases the option-value of waiting with respect to posting new vacancies. The decline in vacancies gives rise to higher unemployment, putting further downward pressure on prices, causing a fall in inflation.

In a forthcoming paper, Baek (2020) focuses on the role of the asset substitution channel in generating quantitatively important responses to uncertainty shocks.

An increase in dispersion of idiosyncratic returns on investment projects causes entrepreneurs to choose lower level of effort thus, endogenously, making projects even riskier. An increase in uncertainty also increases the marginal cost of loans to entrepreneurs. These effects result in significant deleveraging by entrepreneurs thus causing a slump in investment.

Fernandez-Villaverde and Guerrón-Quintana (2020) discuss other channels which can give rise to quantitatively important responses to uncertainty shocks. These include allowing for low probability but large macroeconomic shocks (e.g. rare disasters). Fernandez-Villaverde and Guerrón-Quintana also show that, in the context of open economy models, the presence of multiple assets can further amplify the contractionary effect of uncertainty shocks. Finally, they discuss scenarios under which uncertainty shocks can be expansionary.

This paper particularly focuses on understanding inflation responses to uncertainty shocks in NK models. Though different modelling choices adopted in above mentioned literature help match empirical responses for inflation, these papers do not allow for heterogeneity in inflation responses. The paper also complements the growing literature exploring different channels through which uncertainty affects the economy.

3 Model

The model in this paper is based on the Multiple Calvo model (see Kara (2015)).[3] Specifically, we add heterogeneity in price stickiness suggested by micro-data on price changes to an otherwise standard NK model. The model further allows for trend inflation.

To model heterogeneity in price stickiness, first, as in the standard model, we allow for a continuum of firms $f \in [0,1]$ and assume that each firm f produces a differentiated good in an imperfectly competitive market. Next, following Dixon and Kara (2011), we split firms into N segments according to how frequently firms adjust their prices. We refer these segments as sectors. Finally, we assume that within each sector i (where $i = 1...N$), firms set their prices according to a Calvo-style contract with varying expected duration. The share of each sector i is given by α_i and the sector-specific Calvo hazard rate is $1 - \zeta_i$. The only commonality between firms within each sector is the duration of price contract. When we assume that there is only one sector in the economy (i.e. N=1), we obtain the standard new Keynesian model with Calvo pricing.

We define the cumulative share of sectors as $\hat{\alpha}_i = \sum_{s=1}^{i} \alpha_s$, where $\hat{\alpha}_N = 1$ and the interval for sector i is $[\hat{\alpha}_{i-1}, \hat{\alpha}_i]$. With these assumptions, consumption aggregate (C_t) and the corresponding general price index (P_t) can be rewritten in terms of sectors as follows.

[3] There are a few papers that study the implications of heterogeneity in price stickiness on macroeconomic dynamics. Important examples include Carvalho (2006) and Le Bihan and Dixon (2012) (see Taylor (2018) for a recent review).

$$C_t = \left[\sum_{i=1}^{N} \int_{\hat{\alpha}_{i-1}}^{\hat{\alpha}_i} Y_{ft}^{\frac{\epsilon-1}{\epsilon}} df \right]^{\frac{\epsilon}{1-\epsilon}} \tag{1}$$

$$P_t = \left[\sum_{i=1}^{N} \int_{\hat{\alpha}_{i-1}}^{\hat{\alpha}_i} P_{ft}^{1-\epsilon} df \right]^{\frac{1}{1-\epsilon}} \tag{2}$$

3.1 Firms

We assume that firms only need labour to produce output. The production function for firm f in sector i is given by:

$$Y_{it}(f) = A_t N_{it}(f) \tag{3}$$

where $Y_{it}(f)$ is firm-specific output and $N_{it}(f)$ is firm-specific labour input in sector i. A_t is aggregate technology shock and is given by:

$$lnA_t = (1-\rho_a)ln\bar{A} + \rho_a lnA_{t-1} + \sigma_t^a \hat{a}_t$$

where ρ_a is the persistence parameter and $\hat{a}_t \sim IID(0, \sigma_t^a)$. The uncertainty shock is characterised by σ_t^a which is time-varying standard deviation of the productivity shock. σ_t^a follows:

$$ln\sigma_t^a = (1-\rho_\sigma)\bar{\sigma}^a + \rho_\sigma ln\sigma_{t-1}^a + \sigma_\sigma \hat{\sigma}_t^a$$

where ρ_σ is the persistence parameter and $\exp(\bar{\sigma}^a)$ is standard deviation of the productivity shock in steady-state. $\hat{\sigma}_t^a$ is the i.i.d. shock with mean zero and standard deviation σ_σ.

Firm f sets a price which maximises expected discounted value of her profits over the expected duration when the firm cannot change her price. We assume that firms set their prices according to Calvo pricing. Specifically, in a given period, only a fraction of firms can reset their prices. We do not assume price indexation. Firms' reset price in sector i is given by:

$$X_{it}^{*} = \left(\frac{\epsilon}{\epsilon - 1}\right) \frac{E_t \sum_{\tau=0}^{\infty} (\beta\zeta_i)^{\tau} \lambda_{t+\tau} (\prod_{s=1}^{\tau} \pi_{t+s}^{\epsilon}) \frac{MC_{it+\tau}}{P_{it+\tau}} Y_{it+\tau}^{d}}{E_t \sum_{\tau=0}^{\infty} (\beta\zeta_i)^{\tau} \lambda_{t+\tau} (\prod_{s=1}^{\tau} \pi_{t+s}^{\epsilon-1}) Y_{it+\tau}^{d}} \tag{4}$$

where β is the discount factor and ζ_i is the probability that a firm in sector i cannot change her price in a given period. X_{it}^{*} is reset price and π_{it} is inflation in sector i. This equation shows that reset price in sector i is a mark-up over marginal cost during the expected duration of the contract. Since there is a distribution of contracts, there is a distribution of reset prices in the MC. Firms' cost minimisation problem gives the following expression for marginal costs in sector i:

$$MC_{it} = \frac{W_{i,t}}{A_t} \tag{5}$$

Finally, $P_{i,t}$ is the sector-specific price index which evolves according to:

$${P_{i,t}}^{1-\epsilon} = \zeta_i {P_{i,t-1}}^{1-\epsilon} + (1 - \zeta_i) {X_{i,t}^{*}}^{1-\epsilon} \tag{6}$$

We discuss the calibration of ζ_i across N sectors in section 4.

3.2 Households

There is also a continuum of households $h \in [0, 1]$. Households choose the path for consumption and labour supply in a way to maximise their expected lifetime utility. We assume a CRRA utility function of the form:

$$\max_{C_{h,t},N_{h,t}} E_t \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_{h,t} - \chi C_{h,t-1})^{1-\sigma}}{1-\sigma} - \psi \frac{N_{h,t}^{1+\varphi}}{1+\varphi} \right) \tag{7}$$

where σ and φ are the inverse of intertemporal elasticity of substitution and inverse Frisch labour supply elasticity, respectively. χ determines habits in household's consumption decision. $C_{h,t}$ is the final consumption good consumed by household h and $N_{h,t}$ is hours worked by household h.[4] Households maximise (7) subject to the following budget constraint:

$$P_t C_{h,t} + \sum_{s_{t+1}} Q(s^{t+1}|s^t) B_h(s^{t+1}) \leq W_t N_{h,t} + B_{h,t} + T_{h,t} + \Pi_{h,t} \tag{8}$$

where $E\big[\sum_{s_{t+1}} Q(s^{t+1}|s^t)\big] = 1/R_t$. s^t denotes the state of economy in period $'t'$ and $Q(s^{t+1}|s^t)$ is the price of one period bond portfolio in state s^{t+1} as expected in current state, s^t. $B_h(s^{t+1})$ represents bond portfolio in s^{t+1} held by household $'h'$. Finally, $T_{h,t}$ is lump-sum taxes and $\Pi_{h,t}$ is lump-sum profits from firms.

3.3 Monetary Authority

The central bank conducts policy according to a Taylor-type rule. The central bank reacts to changes in aggregate inflation and the growth rate of output:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{r_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{r_y} \right]^{1-\rho_r} \tag{9}$$

where $\bar{R}$ and $\bar{\pi}$ are steady-state interest rate and inflation, respectively. ρ_r, r_π and

[4]Note that throughout the paper we drop the index h from consumption. This reflects the standard new Keynesian assumption that there exists complete contingent claims markets for consumption, implying that consumption is identical across all households in each period ($C_{ht} = C_t$).

r_y are constant parameters.

4 Calibration

We use Nakamura and Steinsson (2008) (NS) dataset to calibrate the probability of price change in each sector $(1 - \zeta_i)$ and the corresponding share of each sector in households consumption basket, α_i. Nakamura and Steinsson report the frequency of price adjustment for 272 non-shelter product categories, which cover 70% of the US CPI. Following Kara (2015), we aggregate up the 272 product categories to 10 groups with distinct price reset probabilities. The aggregation is performed by forming probability focal points in increments of 0.1 percentage points [thus: 0.1; 0.2; 0.3 ... 1]. We then round the reset probabilities to 0.1 percentage point and allocate the 272 product categories to these 10 focal points. The groups are scaled by the share in expenditure that is allocated to each focal point. We use this information to calibrate a 10-sector MC. The distribution of frequency of price changes in each sector and the corresponding expenditure share is plotted in Figure 1. An important point to note is that there are plenty of flexible prices in the US economy. The share of flexible prices is around 40%. The distribution also has a long tail. Figure 1 also plots the corresponding distribution implied by the Bils and Klenow (2004) (BK) dataset. As is evident from the figure, the BK distribution is very similar to that suggested by the NS dataset. The average age of price spells is 3 quarters in the NS dataset and 2.5 quarters in the BK dataset. While we use the NS distribution throughout this paper, using the BK distribution does not change our results.

Table 1: **Other Parameters**

Parameters	Values	Parameters	Values
β	0.99	ϵ	10
σ	3	$1/\varphi$	0.5
ψ	8.5	χ	0.65
$\bar{\pi}$	2.5% (annual)	ρ_r	0.5
r_π	1.5	r_y	0.2
ρ_a	0.9	σ_a^2	0.0025
ρ_σ	0.9	σ_σ^2	0.01

Note: *This table provides calibrated values for structural parameters which are similar across sectors.*

Table 1 reports parameter values which are similar across sectors. The calibration of these parameters is standard. Moreover, the value of the persistence parameter of productivity shock, ρ_a, equals 0.9 whereas its standard deviation, σ_a, equals 0.05. Values for parameters governing the uncertainty shock process, ρ_σ and σ_σ, are 0.9 and 0.1, respectively. We calibrate trend inflation, $\bar{\pi}$, to 2.5% which is the average inflation rate over the last three decades. We discuss the role of trend inflation in propogating the effect of uncertainty shocks in the next section.

5 Results

We start with describing the effects of increasing uncertainty in both the standard model with Calvo pricing and the MC model. Figure 2 plots impulse response functions (IRFs) to an uncertainty shock implied by both models.To examine the macroeconomic effects of uncertainty shocks, as such shocks are second-moment shocks, we solve the model by taking third-order Taylor approximation of equilibrium conditions around the steady state. A key difference between the two models arise when it comes to how prices and inflation responds to the increase in uncertainty.

If we look at the IRFs of the price level implied by the Calvo model, we see that there is a permanent increase in the price level in response to an uncertainty shock. On the other hand, in the MC, the price level adjusts in a hump-shaped manner. An increase in uncertainty leads to a fall in the price level in the MC, which then recovers after some time of the shock. As a result, while inflation increases in the Calvo model, it decreases in the MC. We will discuss these differences in firms' price setting behaviour in more detail in next section.

Both models imply that output falls in an event of an increase in uncertainty. The reason for this result is twofold. First, an increase in uncertainty decreases households' demand for consumption goods due to precautionary motives, causing output to fall. Second, an increase in uncertainty also causes firms' to increase their markups which further puts a downward pressure on output. Since markups increase by more in the MC model (see Figure 2), an uncertainty shock results in a much larger contraction in output than in the Calvo model. Moreover, it also takes longer for output to return to its trend.

Moreover, since the central bank sets interest rate following a Taylor-type rule, the response of interest rate reflects the behaviour of inflation in each model. The nominal interest rate falls due to the fact that both inflation and output fall on impact of the shock in the MC. Whereas, in the Calvo model, since increased uncertainty leads to an increase in inflation, the nominal interest rate increases on impact before gradually returning to its steady-state value.

Next, we comment on the behaviour of marginal costs before moving to the main focus of this paper in following sections. The drop in output results in a fall in marginal costs in both models. However, it is interesting to note that, on impact of the shock, marginal costs fall less in the MC than in the Calvo model. Whereas, in the latter part of the adjustment process, marginal costs are relatively lower in the MC than in the Calvo model. To understand this, first note that sectors with sticky prices put downward pressure on marginal costs, while those with flexible prices put upward pressure. These results are a consequence of the fact that sticky-price firms increase their prices, while flexible-price firms decrease their prices. Increased prices in the sectors with sticky prices has contractionary effect on output and marginal costs. In contrast, fall in prices in flexible-price sectors has a positive effect on marginal costs, as the demand for factor inputs would be higher than otherwise. Since prices in flexible price sectors change more in response to the shock, at the onset of the shock, such prices play a more important role than the sticky-prices. As a result, on impact, marginal costs fall less in the MC than in the Calvo model. After some time of the shock, since firms with flexible prices have already adjusted their prices, sticky-price firms dominate the adjustment process. Therefore, in the latter period, marginal costs become relatively lower in the MC than in the Calvo model.

Finally, it is worth pointing out that responses implied by the MC model capture responses reported in empirical studies (see, e.g., Fernandez-Villaverde et al.) better than the Calvo model.

5.1 Why does inflation fall in the MC?

The findings reported above raise an important first question: why is it that inflation falls in the MC but increases in the Calvo model? To answer this question, we start by discussing what is already known from the work based on the Calvo model. In standard New Keynesian models, an uncertainty shock affects the economy through the contractionary demand channel and the upward-pricing bias channel. The contractionary demand channel causes households to decrease their demand for consumption goods due to precautionary savings motives thus putting a downward pressure on both output and inflation. The upward-pricing bias channel is only relevant when prices are sticky. This channel leads firms to increase their prices in response to an uncertainty shock, putting a downward pressure on output but an upward pressure on inflation. It turns out that the upward-pricing bias channel dominates the contractionary demand channel in the standard model thus causing inflation to increase in response to the shock.[5]

Understanding the upward-pricing bias channel is important for results in this paper. The upward bias in firms' pricing decisions is due to asymmetry in firm's profit function which implies that losses are higher when firm's price relative to her competitors is lower than when it is higher (Fernandez-Villaverde et al., 2015). The reason for this result is that firms with lower prices face a higher demand for their products and do much of the production. Consequently, as diminishing marginal returns kick in, production becomes less profitable. Therefore, when relative price is low, higher marginal profit creates an incentive for firms to increase their prices.

[5]This result also holds for preference and policy shocks.

Since prices are sticky and an increase in uncertainty increases the probability that a firm's relative price may be even lower in future, firms allow for precautionary markups and bias their prices upwards in an attempt to self-insure against future states with lower relative prices. It is this increase in precautionary markups that lead to higher prices and, therefore, higher inflation following an uncertainty shock in the Calvo model.

With vital bits of intuition now in hand, we now turn to the MC model. As in the Calvo model, both the contractionary demand and the upward-pricing bias channel play an important role in determining inflation dynamics in the MC. However, in addition to these channels, the presence of heterogeneity in price stickiness in the MC has a crucial role in the dynamics of the model. Heterogeneity in price stickiness leads to heterogeneity in precautionary markups and, consequently, heterogeneity in sectoral inflation responses.

In the MC, in sectors with relatively flexible prices, precautionary markups are smaller than those in sectors with sticky prices. This point is easy to understand. In sticky price sectors, since the expected duration of price contracts is longer, firms set higher markups to self-insure against possible future states with lower relative prices. In contrast, firms with relatively flexible prices need not worry about the future as much as the sticky price firms. This is because such firms are more likely to revise their prices on impact or soon after the shock. As a result, in any given period, these firms set a lower precautionary markup. To confirm these suggestions, figure 3 plots magnitude of price markups on impact of the shock across sectors in the MC. As a point of reference, we also include the impact markup in the single-sector Calvo model. As the figure shows, the size of markups increase with the degree of price stickiness.[6]

The heterogeneity in precautionary markups has important implications for sectoral inflation responses and, as a result, for aggregate inflation. Lower markups in sectors with relatively flexible prices means that the upward pricing bias channel is weak and, consequently, inflation is determined by the contractionary demand channel. Whereas, in sectors with sticky-prices, significantly higher markups put upward pressure on prices and, consequently, on inflation. In figure 4, we plot sector-specific inflation responses from the MC model. As is evident from the figure, following the shock, inflation falls in relatively flexible sectors (i.e. from sector 1 to sector 6) but increases in sectors where prices are relatively sticky (i.e. from sector 7 to sector 10). Inflation also changes by more in sectors with flexible prices relative to those with sticky prices. Moreover, since around 60% of firms belong to sectors where inflation falls, these factors imply that aggregate inflation falls in response to an uncertainty shock.

5.2 The Role of Trend Inflation

The results presented so far assume positive trend inflation. This section discusses the role of trend inflation in more detail. Figure 5 plots impulse responses to an uncertainty shock from the benchmark MC model (red line) where trend inflation

[6]It is interesting to note that even in the sector with fully flexible prices, the change in markups is positive. The reason for this is similar to one provided above. The relative price of firms in flexible sectors decreases after firms in sticky sectors increase their prices. Since firms' profit function is asymmetric, profits in flexible sectors decline. Therefore, price setting firms in these sectors require additional markups to avoid losses due to lower relative prices.

equals 2.5% and two other versions of the model where trend inflation equals 0% (dashed blue line) and 4% (dashed-dotted black line).

A key result that stands out is that higher trend inflation amplifies the contractionary effect of uncertainty shocks on the economy. As trend inflation increases, output contracts more and also recovers much slowly.[7] This is due to several reasons. First, as figure 5 shows, higher trend inflation results in a bigger increase in price markups. Most of this increase comes from a disproportionately large increase in precautionary markups in sticky-price sectors. This is because, in presence of positive trend inflation, firms' relative price in sticky sectors may end up much lower than their competitors. Therefore, since trend inflation would disproportionately erode firms' profits in sticky sectors, self-insurance requires that these firms allow for much bigger precautionary markups when setting their prices.

Second, higher trend inflation increases inertia in the economy which not only amplifies the effect of shocks but also makes these more persistent. Ascari (2004) explains why this happens. An increase in trend inflation increases price dispersion. As a result, firms with lower relative prices produce more whereas firms with higher relative prices produce less. The "non-linearity of the Dixit-Stiglitz consumption basket" then implies that it takes more resources "to produce one unit of that basket" than before. In the MC model considered in this paper, price dispersion increases significantly more with trend inflation relative to the standard Calvo model. As a result, with an increase in trend inflation, output contracts more in response to the

[7]This result also holds in the standard model except that inflation ends up increasing even more. Therefore, trend inflation worsens the match between the standard model and data even further.

shock.

Trend inflation also helps the MC match the empirical response of price level to the shock. In presence of trend inflation, heterogeneity in pricing behaviour across sectors in the MC results in aggregate inflation moving above its target value during latter part of the adjustment process. This happens because, after some time of the shock, since firms with flexible prices have already adjusted their prices, sticky-price firms start to dominate the adjustment process. Since inflation increases in these sectors following the shock, aggregate inflation moves above the target level. The overshooting of inflation in the later period helps the price level recover back to its trend.

These results are revealing especially in the context of recent policy proposals to increase the inflation target to 4%. The figure shows that with $\bar{\pi} = 4\%$, the fall in output is twice as large as with $\bar{\pi} = 2.5\%$. This result highlights that a higher inflation target would intensify the disruptive effect of increased uncertainty on the economy.

5.3 Monetary policy regime

Thus far, in our analysis, we have assumed that monetary policy is set according to an inflation targeting policy. Recently, the FED shifted to a price level targeting rule from an inflation targeting rule. In particular, the Fed chairman Jerome Powell pointed out:

> *"We will seek to achieve inflation that averages 2 percent over time. Therefore, following periods when inflation has been running below 2 percent, appropriate monetary policy will likely aim to achieve inflation moderately above 2 percent for some time."*
>
> **- Fed. Chairman Jerome Powell**

We now turn to examine the effectiveness of such a price level targeting policy in the presence of increasing uncertainty.[8] To this end, we replace the Taylor-rule in equation (9) with the price-level targeting rule (i.e. eq. 10) and repeat experiments in previous sections. Specifically, we adopt the following price-level targeting rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left[(\hat{P}_t)^{r_{\hat{p}}} \left(\frac{Y_t}{Y_{t-1}}\right)^{r_y}\right]^{1-\rho_r} \tag{10}$$

where $\hat{P}_t$ is the deviation of aggregate price level from its trend and $r_{\hat{p}}$ is the weight central bank attaches to stabilising the price level.

Figure 6 plots IRFs from the benchmark model and also from the model where the central bank stabilises deviations in price level. An interesting result emerges from

[8] Eggertsson and Giannoni (2020) explore the effectiveness of the new regime when the economy is at the zero lower bound.

the figure. The figure shows that the contractionary effect of uncertainty shocks is much smaller under price level targeting. In fact, under price level targeting, relative to the inflation targeting policy, the disruptive effect of increasing uncertainty is almost non-existent.

What is the intuition behind this result? To understand this result, first recall that the source of the disruptive effect of increasing uncertainty is the increase in likelihood that firms' prices may end up lower than their competitors in future. To self-insure, firms increase their prices more than they otherwise would have. In contrast, under price level targeting, since the central bank commits to keeping prices stable, uncertainty regarding future relative prices is lower. This reduction in uncertainty about relative prices reduces the need for self-insurance against future states with lower relative prices. As a result, under price level targeting, in response to increasing uncertainty, firms do not increase their prices as much as they do under inflation targeting. Consequently, this reduces the contractionary effect of increasing uncertainty. Moreover, by making future prices and, therefore, households' (real) lifetime wealth more certain, the motive for precautionary savings reduces as well. Taken together, the decrease in precautionary markups and lower precautionary savings motives results in a much smaller decline in prices and output.

Finally, price level targeting also reduces the role heterogeneity in price stickiness plays in firms' pricing decisions across sectors. Figure 7 repeats the exercise performed in figure 3. Unlike under inflation targeting, the magnitude of precautionary markups is close to zero across all sectors under price level targeting.

6 Robustness: Rotemberg pricing and structural parameters

Throughout the paper we assumed that firms set their prices according to Calvo (1983). Under Calvo pricing, since there is always a possibility that a firm may not get a chance to reset her price in any given period, firms must be significantly more forward looking when setting their prices. This amplifies the precautionary bias channel in the model and, consequently, affects inflation and output dynamics as explained in section 5.1.

We now test the robustness of our results to an alternative price setting. Specifically, we replace Calvo pricing with Rotemberg pricing. The rest of our assumptions are the same as before. Results from tests we conducted (not reported but available upon request) suggest that all our conclusions carry over to a setting with Rotemberg pricing. The only difference between the two cases is that the effect of the shock is smaller in the case with Rotemberg pricing. This result is easy to understand. A key difference between the two pricing models is that, unlike under Calvo pricing, firms do not need to worry as much about getting stuck with the same price for a long-time. As a consequence, the self-insurance motive under Rotemberg pricing is weaker than under Calvo pricing, resulting in smaller precautionary markups in the Rotemberg model than in the Calvo model. Since markups increase by less under Rotemberg, the disruptive effect of the shock is smaller under Rotemberg than under Calvo.

The structural parameters which play an important role in driving firm's price setting behaviour include the parameters of Taylor rule, the inverse of Frisch elasticity of labour supply and the persistence parameter of the uncertainty shock process. The Taylor rule parameters for inflation and output determine how much the central bank cares about stabilising inflation relative to output. When the central bank cares more about stabilising output (i.e. low r_π, high r_y or both), future prices become more uncertain thus increasing the magnitude of desired precautionary markups for self-insurance. Consequently, while inflation still falls in the MC model, it falls by less and also recovers faster following the shock. Our results are, however, robust for parameter values in the neighbourhood of the baseline calibration. Moreover, the mismatch between the standard Calvo model and data becomes even stark.

A lower Frisch elasticity of labour supply also plays an important role in how firms respond to uncertainty shocks. Assuming this to be close to zero takes the inflation response in the standard Calvo model closer to data. For example, while decreasing Frisch elasticity from the baseline value of 0.5 to 0.25 still leads to an increase in inflation on impact in the standard Calvo model, inflation moves below its steady-state value from second quarter onwards. Despite this, it is important to note that a lower value for Frisch elasticity implies that inflation falls even more in a model incorporating heterogeneity in firms' price setting behaviour (i.e. the MC).

Finally, if the uncertainty shock is less persistent, the upward pricing bias channel is stronger and inflation increases by more in response to an uncertainty shock in the standard Calvo model. While inflation still falls on impact of the shock in the MC, it moves above its steady-state immediately after. In contrast, under Rotemberg pricing, the model with heterogeneity continues to capture inflation response well.

7 Conclusion

We have examined the effects of increasing macroeconomic uncertainty using the standard new Keynesian model and a multi-sector version of it that accounts for the heterogeneity in price stickiness suggested by micro-data on prices − a Multiple Calvo (MC) model. We have also considered two alternative policy rules: price-level targeting and inflation targeting. In our analysis, we further allow for positive trend inflation. Three interesting results emerge from the analysis.

First, in the MC model, both output and aggregate inflation decline following an uncertainty shock. This is because, unlike in the standard model with Calvo pricing, the MC approach allows for the possibility that different sectors across the economy can respond differently to increasing uncertainty. We find that how a sector is affected by an uncertainty shock depends crucially on the degree of nominal rigidity in that sector. When setting a new price, firms in sectors with a higher degree of nominal rigidity set higher price markups. This is because the price set is expected to remain unchanged for a longer duration. By setting a higher markup, these firms self-insure themselves against increased uncertainty. It turns out that despite the fact that aggregate demand falls following the shock, prices in these sectors increase. On the other hand, in sectors with a lower degree of nominal rigidity, markups are smaller, as firms in these sectors frequently get the chance to reset their prices optimally. Therefore, in such sectors, the aggregate demand channel dominates and inflation falls. Since the initial part of the price adjustment process is dominated by sectors with relatively flexible prices, aggregate inflation falls in response to an uncertainty shock.

Second, price level targeting helps to mitigate the disruptive effect of increasing uncertainty better than inflation targeting. This is because, under price level targeting, relative prices are more stable thus reducing the need for precautionary price markups. Moreover, higher certainty about prices also reduces the need for precautionary savings.

Finally, positive trend inflation amplifies the effects of uncertainty shocks. We find that when we calibrate trend inflation to its historical value (i.e. 2.5%), our model predicts that output falls significantly more than in the case with the standard zero-trend inflation assumption.

Our findings have two implications for recent macroeconomic discussions. First, the finding that positive trend inflation amplifies the effects of uncertainty shocks provide a case against the recent policy proposal to increase the inflation target from 2% to 4%. Second, our result that price level targeting performs better than inflation targeting in mitigating the effect of uncertainty shocks provides a theoretical justification for the FED's average inflation targeting policy.

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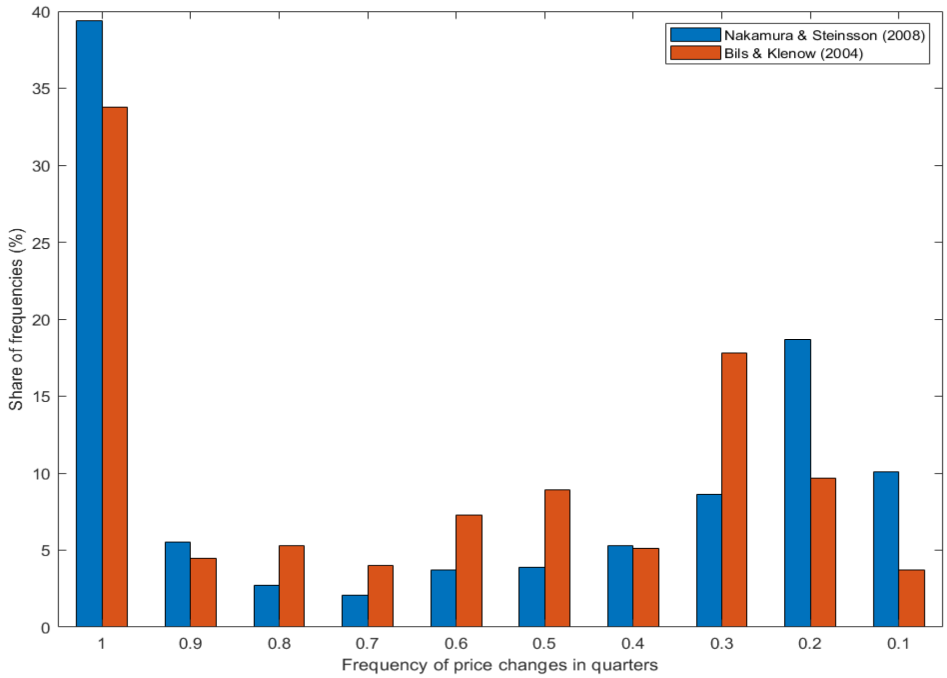
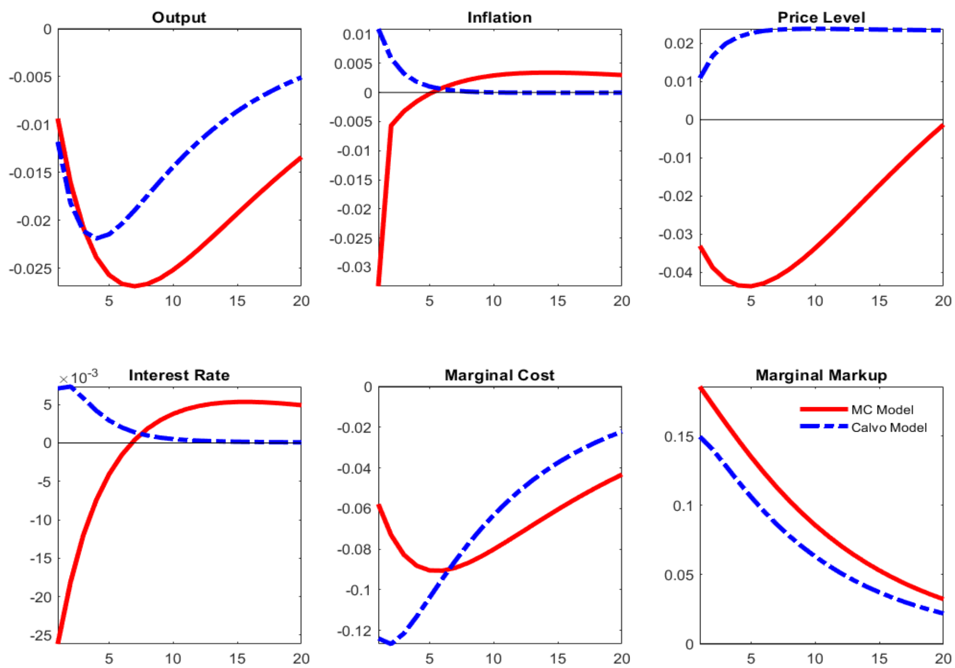
Figure 1: **Sectors' Weights & Frequency of Price Changes**



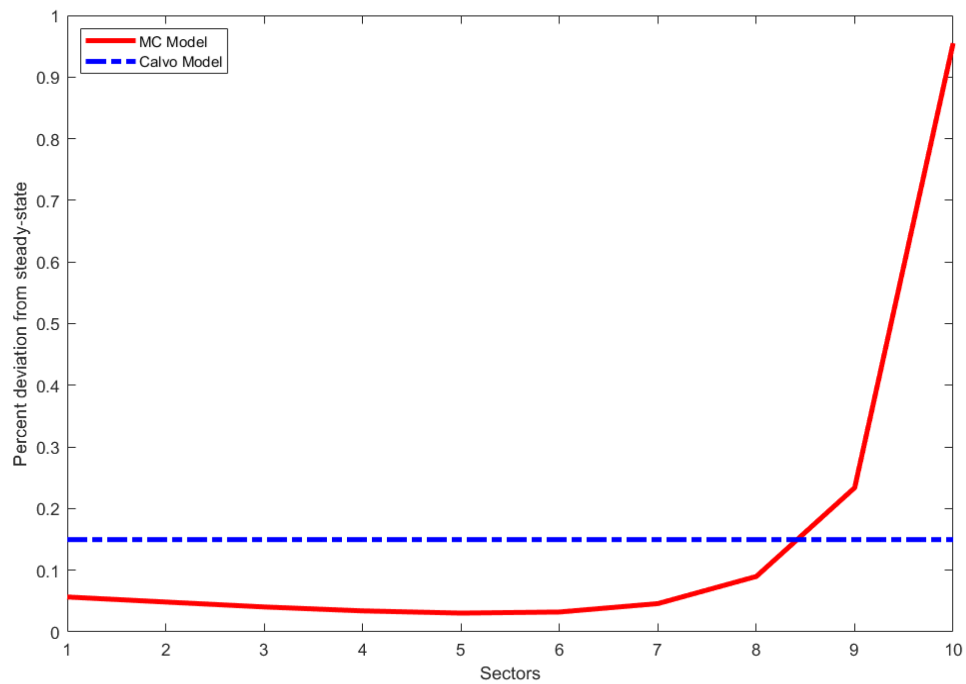
Notes: The figure plots consumption shares of each of 10 sectors together with corresponding frequency of prices changes.

Figure 2: **Impulse responses to an uncertainty shock in Calvo and MC models**



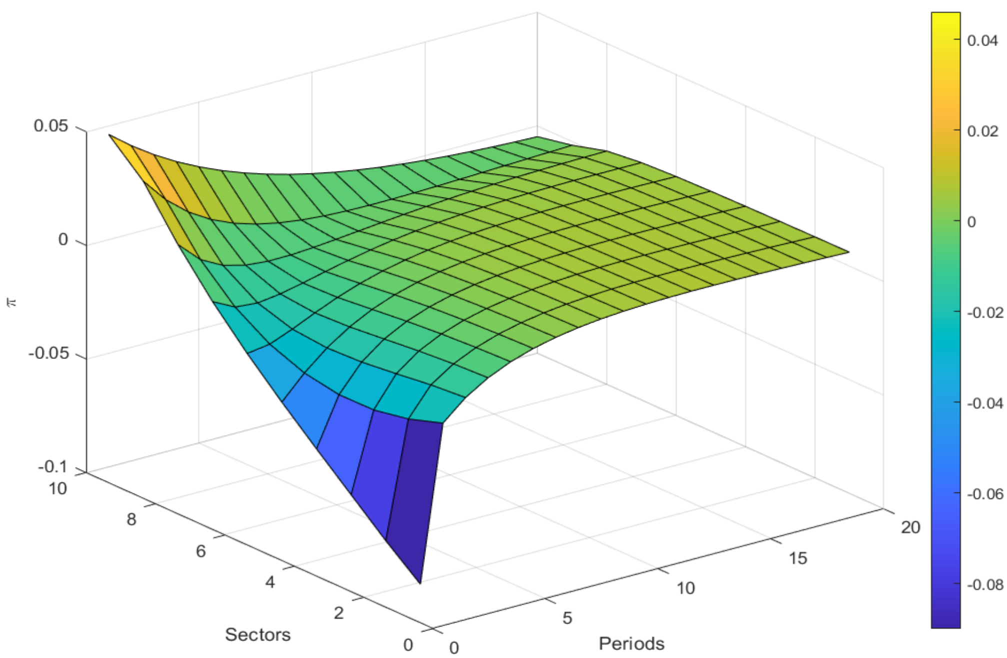
Notes: The figure plots impulse responses to a 100% increase in uncertainty. The dash blue line represents responses from the Calvo model. The solid red line represents responses from the MC model. Deviation in Inflation and Interest rate are plotted in terms of percentage points whereas for all other variables it is plotted in terms of percentage from steady-state.

Figure 3: **Impact Price Markups across sectors in the MC model**



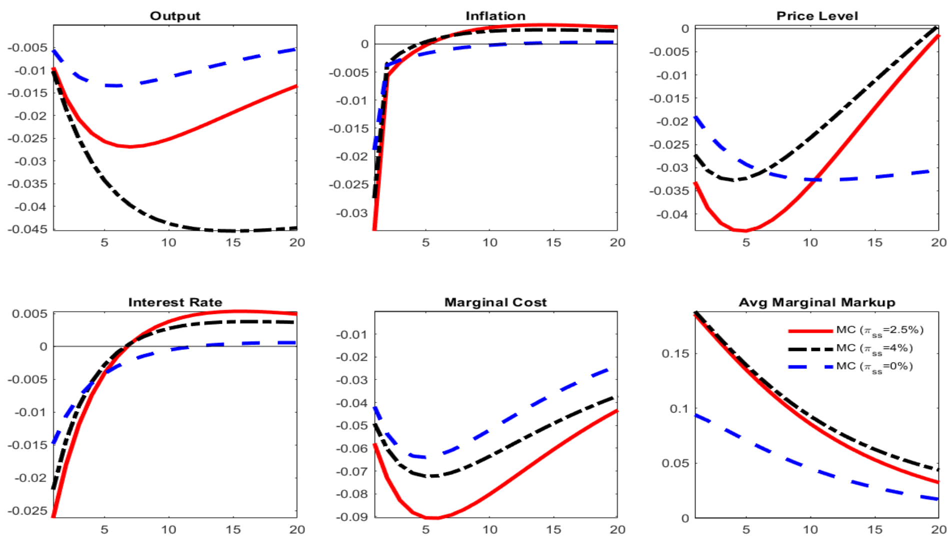
Notes: The figure plots impact price markups to a 100% increase in uncertainty across sectors. Sectors are ordered in increasing order with respect to degree of price stickiness such that sector 1 is most flexible and sector 10 is least flexible. The solid red line represents impact response for price markups from the Multi Calvo model whereas the dash blue line represents those from the standard Calvo model.

Figure 4: **Sectoral Inflation: IRFs to an uncertainty shock**



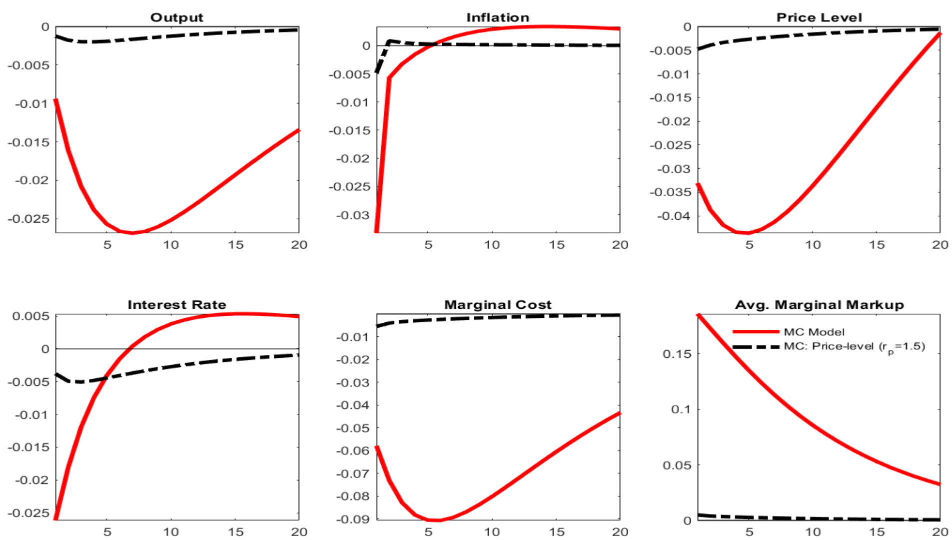
Notes: This figure plots how inflation across sectors evolves over time in response to an uncertainty shock. Results show that an uncertainty shock decreases inflation in sectors with relatively flexible prices whereas inflation increases in the sticky price sectors.

Figure 5: **Impulse responses to an uncertainty shock in the MC for different values of trend inflation**



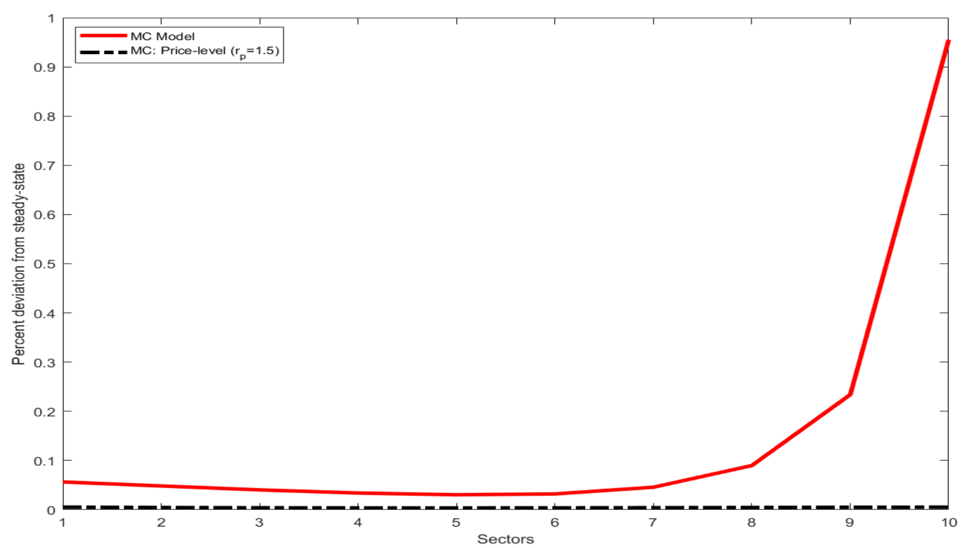
Notes: The figure plots impulse responses to a 100% increase in uncertainty for different values of trend inflation ($\bar{\pi}$).

Figure 6: **Impulse responses under Inflation and Price-level targeting**



Notes: The figure plots impulse responses to a 100% increase in uncertainty under different monetary policy rules: Inflation targeting (IT) and Price-level targeting (PLT).

Figure 7: **Impact Price Markups across sectors under Inflation and Price-level targeting**



Notes: The figure plots impact price markups to a 100% increase in uncertainty across sectors under Inflation Targeting (IT) and Price-level Targeting (PLT). Sectors are ordered in increasing order with respect to degree of price stickiness such that sector 1 is most flexible and sector 10 is least flexible. The solid red line represents responses under IT whereas the dashed black line represents responses under the PLT.