Monetary Policy Uncertainty and Firm Dynamics*

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Abstract

This paper uses a FAVAR model with external instruments to show that monetary policy uncertainty shocks are recessionary and are associated with an increase in firms' exit and a decrease in firms' entry. At the same time, the stock price declines, while the TFP increases in the medium run. To explain this result, we build up and estimate a medium-scale DSGE model featuring firm heterogeneity and endogenous firm entry and exit. These features are crucial in matching the empirical responses. The baseline model outperforms an alternative model without firm dynamics in reproducing the FAVAR responses and implies a larger effect of monetary policy uncertainty shock on the real economic activity.

Key words: Monetary policy uncertainty, Firm dynamics, FAVAR, DSGE.
JEL codes: C5, E1, E5, E52

1 Introduction

Global events such as the Great Recession and the ensuing slow recovery, the sovereign debt crisis in Europe, Brexit, and the Covid-19 pandemic, all contributed to the increase in macroeconomic uncertainty in developed countries. The recent experience has shown that sharp and timely interventions of policymakers may be crucial in times of economic distress. Announcements of policy strategies that aim to foster recovery have often helped to reassure financial markets and significantly reduce uncertainty. Instead, delayed and unclear responses by policymakers may fuel uncertainty and, likely, curb economic activity. Although the literature agrees on the recessionary effects of uncertainty shocks, the impact of heightened uncertainty about the action of policymakers and in particular, of the monetary authority is less clear. Some previous studies find that policy uncertainty influences capital flows, the business cycle, and the speed of economic recovery (Mumtaz and Zanetti (2013), Fernández-Villaverde et al. (2015), Baker et al. (2016), Mumtaz and Surico

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(2018), Bloom et al. (2018), Caggiano et al. (2020)).[1] Other contributions document that monetary policy uncertainty affects a broad range of asset prices, including bonds, stocks, and exchange rates (Swanson (2006), Istrefi and Mouabbi (2018), Creal and Wu (2017), Bundick et al. (2017), Husted et al. (2019), Bauer et al. (2021)). In this paper, we revisit the question and consider the role of firm dynamics in propagating the impact of monetary policy uncertainty shocks. We refer to monetary policy uncertainty as to the perceived uncertainty that economic agents have about the possible realizations of future monetary policy. In particular, we investigate the effects of heightened uncertainty about the future short-run interest rate both in the data and in theory. To study the transmission of monetary policy uncertainty shocks, in the empirical analysis, we rely on a market-based measure of uncertainty about the future short-term interest rate. In the model, we inspect the dynamics by implementing innovations to the time-varying volatility of the monetary policy shock. We investigate the importance of firms' entry and exit decisions for the transmission of monetary uncertainty shocks. When monetary policy is uncertain, households and firms are unsure about the value of interest rates and inflation. For the productive sector, this uncertainty has also implications for the decisions of participating in the market. Firms that become more unsure about whether the discounted future cash flows will cover the cost of entry might decide to not enter the market. Firms that become more unsure whether the discounted future cash flows will guarantee the break-even and thereby, production might decide to exit from the market. Overall, the increased uncertainty about monetary policy might imply a lower entry and higher exit of firms, which ultimately, affect economic activity.

In the first part of the paper, we investigate the transmission channel of firm dynamics for monetary policy uncertainty shocks for the US economy over the period 1985:m1 to 2016:m6. We study the transmission in a FAVAR model, where the monetary volatility shocks are identified through an external instrument as in Husted et al. (2019).

Although we are interested in evaluating the conditional responses of entry and exit to increased monetary policy uncertainty, it is interesting to examine the comovement between monetary policy uncertainty and firm dynamics. We thus conduct an investigation on the relationship between the raw data of MPU index by Husted et al. (2019) and of entry and exit over the same sample of the FAVAR analysis. Figure 1 reports the unconditional cross-correlations between the moving average of total entry/total exit and lags and leads of the MPU index. The figure shows that lags of the MPU index are negatively correlated with total entry and positively correlated with firm exit. This provides prima facie evidence that higher MPU is associated with lower firm births in the future while firm deaths are expected to increase.[2]

The impulse responses to monetary policy uncertainty shocks obtained from the FAVAR show that shocks increasing monetary policy uncertainty are recessionary. Moreover, firms' births decrease, while firms' deaths increase.[3] This evidence is robust both at the aggregate level, namely for establishments' births and deaths in the total private sector, and at the industry level.[4] The stock price decreases in response to higher monetary policy uncertainty, and similarly to Bloom (2009), the utilization-adjusted TFP series reacts negatively on impact but overshoots in the medium-run.

[1] On the opposite, Born and Pfeifer (2014) claim that policy risk is unlikely to play a major role in business cycle fluctuations, with their DSGE model suggesting that policy uncertainty shocks are small and their impact is not sufficiently amplified.

[2] It is worth stressing that these results do not depend on the sample. If the sample is restricted to 2007:m12, then the correlation between MPU and entry is negative even contemporaneously while the lag between higher MPU and higher exits is smaller. We show this figure in the Technical Appendix.

[3] Notice that in the paper we use entry and exit and birth and death as synonymous.

[4] In the empirical analysis, we report evidence at the industry-level to show that the effect of monetary policy shocks is general and hits most of the sectors. We do not analyse the dynamics at the industry-level even in the theoretical model as it is not the aim of this paper to focus on sectoral relationships.

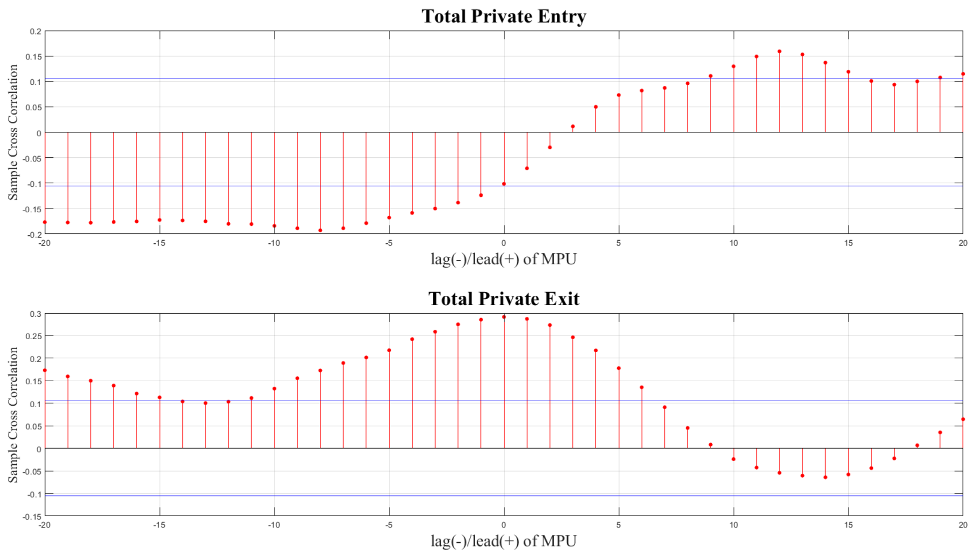

Figure 1: Cross-correlations between MPU index and total private Establishment Entry and Exit.

We rationalize the empirical evidence on monetary policy uncertainty shocks in the second part of the paper. We consider a medium-scale New Keynesian model extended by adding firm heterogeneity and endogenous firm entry and exit. In the intermediate sector, firms are heterogeneous in terms of their specific productivity. Similar to Rossi (2019), firms decide to produce as long as their specific productivity is above a cut-off level, which is determined by the level of productivity that makes the present discounted value of the stream of profits equal to the firms' liquidation value. The defaulting probability for firms is endogenously determined by the cut-off level of productivity. The advantage of this framework is that firms' exit and average productivity evolve endogenously, bringing about endogenous TFP variations. During a recession, firms with specific productivity below an endogenous threshold exit the market, so that the average productivity and the TFP increase. The opposite occurs in an expansionary period. As in the seminal contribution by Bilbiie et al. (2012), firms enter the market up to the point where the expected discounted value of the future profits equals the sunk cost of entry. The investment in new firms is financed by households through the accumulation of shares in a portfolio of firms. This implies that the stock price fluctuates endogenously in response to shocks.

Using the theoretical model, we estimate a set of structural parameters and quantitatively assess the importance of entry and exit for the transmission of the shock to the economic activity. To better understand the role of firm dynamics we estimate the same model without firm dynamics. Both models are estimated using limited information impulse response functions matching techniques (in the spirit of Christiano et al. (2005), Basu and Bundick (2017), Mumtaz and Theodoridis (2019)). For both models, the data used in the estimation are the FAVAR-implied responses of the growth rate of real GDP, consumption, investment, consumer price index, and one-year government bond rate. The estimated models are used to calculate the responses of the variables to an unexpected increase in monetary uncertainty. The baseline model with firm dynamics produces an amplification of the shock with respect to the model without firm dynamics. Importantly, the estimates indicate that our baseline model requires a lower degree of price rigidity and nominal wage rigidity than the model without entry and exit. In this respect, we find our empirical result consistent with the recent theoretical result shown by Bilbiie and Melitz (2020). The two authors show that a simple NK model with endogenous entry-exit amplifies the response of economic activity to shocks when the model is approximated to an order higher than one. We show that with this amplification due to frictional entry, our baseline model requires a lower degree of nominal rigidities. Furthermore, the degree of wage rigidities estimated in our baseline model is higher than price rigidities, thus being in accordance with the empirical literature. The baseline model is more in line with the empirical evidence provided by the FAVAR model than the model without firm dynamics. By construction, the model with constant firms cannot replicate the dynamics of firm entry and exit. In that model, responses of the TFP and stock price are muted. Moreover, the fall in output, consumption, investment in physical capital is lower than in the baseline model. We take the results as an indication that both firm dynamics and firm heterogeneity are crucial in allowing the theoretical framework to replicate the evidence found in the FAVAR analysis.

This paper relates to two main strands of literature. It relates to the literature studying the macroeconomic effects of policy uncertainty shocks. Second, it adds to the literature investigating the role of firm dynamics for the business cycle analysis. After Bloom (2009), many papers discuss the macroeconomic impact of uncertainty shocks.[5] Among them, some contributions focused on the consequences of policy-related uncertainty shocks over the business cycle, e.g. Fernández-Villaverde et al. (2015), Born and Pfeifer (2014), Mumtaz and Surico (2018). Overall, this literature points to the relevance of uncertainty shocks in explaining a large share of the fluctuations in the business cycle, and the contractionary effects on the main real variables, namely output, employment, consumption, and investment. Several contributions also drew on the availability of measures of policy uncertainty to evaluate the impact of these shocks on the economy. Considering monetary policy uncertainty, Baker et al. (2016) and Husted et al. (2019) construct text-based measures of uncertainty Istrefi and Mouabbi (2018) build up a measure of uncertainty stemming from the disagreement among professional forecasters on short- and long-run interest rates. Using a term structure model, Creal and Wu (2017) estimate the stochastic volatility of the monetary policy rule. Swanson (2006), Bundick et al. (2017), Bauer et al. (2021) use market-based measures of monetary policy uncertainty to document the effects on the financial market. This paper relates to this literature using a market-based measure of monetary policy uncertainty in the empirical analysis and assuming stochastic volatility in monetary policy shocks in the model. Importantly, this paper highlights the importance of the firm dynamic channel to interpret monetary policy uncertainty shocks. Most of the previous literature on the economic impact of higher monetary policy uncertainty indeed limited the analysis to the effects on the intensive margin of investment, that is on the decisions about new investments of firms already participating in the market. Surprisingly, the effects of uncertainty shocks on the extensive margin of investment concerning the firms' decisions about participating in the market have been largely ignored in the literature. To our knowledge, only Brand et al. (2019) has already studied in a macroeconomic model the effects of second-moment shocks on firm creation and destruction. Brand et al. (2019) build up and estimate a theoretical model with search and monitoring costs in the credit market to study how the higher dispersion in firm productivity affects macro-financial aggregates and firm dynamics. We differ from their contribution along at least three dimensions. First, they provide an alternative way to formalize firm dynamics based on search frictions between entrepreneurs and banks. Second, while we focus on the effects of monetary policy uncertainty shocks, they consider uncertainty in firms' idiosyncratic productivity. Third, they do not provide evidence on firm dynamics at the industry level.

[5] For instance, Fernández-Villaverde et al. (2011), Gilchrist et al. (2013), Caggiano et al. (2014), Christiano et al. (2014), Bachmann and Bayer (2014), Leduc and Liu (2016), Caldara et al. (2016), Basu and Bundick (2017), Bloom et al. (2018), Mumtaz and Theodoridis (2019).

The impact of firm dynamics on business cycle fluctuations has been extensively studied in papers investigating the effects of first moment shocks, that is level shocks. The seminal paper by Bilbiie et al. (2012) in the DSGE literature shows that endogenous entry generates a new and potentially important endogenous propagation mechanism for real business cycle models. Among others, Jaimovich and Floetotto (2008), Lewis and Poilly (2012), Etro and Colciago (2010), Clementi and Palazzo (2016), Lewis and Stevens (2015) provide evidence that the number of producers varies over the business cycle and that firm dynamics may play an important role in explaining business cycle statistics. Bilbiie et al. (2014) consider a DSGE model with monopolistic competition and sticky prices and find that deviations from long-run stability of product prices are optimal in the presence of endogenous producer entry and product variety, whereas price stability would be optimal in the absence of entry. Hamano and Zanetti (2014) and Casares et al. (2020) introduce endogenous firms exit in a DSGE model, but consider different timing and exiting schemes. While Hamano and Zanetti (2014) study the effects of a negative technology shock in a simple RBC model, Casares et al. (2020) consider a medium-scale model and estimates the effects of a set of level shocks on business cycle dynamics. Different from our framework, in their paper firms exit at the end of the production period, implying that the average productivity remains exogenous and constant even in the short run. This prevents the TFP from varying along the business cycle. Closer to our theoretical framework is Rossi (2019), who however considers a simple small-scale New Keynesian model with endogenous entry and exit interacting with banking frictions to study the effects of first-moment shocks to the aggregate productivity level.

Our paper then makes two clear contributions. First, it extends the literature on policy uncertainty shocks by considering the role of firm dynamics from an empirical and theoretical perspective. To the best of our knowledge, the role of firm dynamics in propagating a monetary policy uncertainty shock has not been investigated in the existing literature. We show that this feature is a crucial component in amplifying the effect of this shock in DSGE models. Second, from an econometric perspective, the paper proposes a FAVAR model that allows for mixed-frequency and missing data, allowing us to utilize series on aggregate and industry-specific firms' entry and exit which are available at a lower frequency and contain missing observations.

The remainder of the paper is organized as follows. Section 2 introduces the FAVAR model and provides empirical evidence. Section 3 spells out the DSGE model economy. Section 4 describes how we set the structural parameters of the DSGE and shows dynamics that follow the monetary policy uncertainty shock. Finally, Section 5 concludes. Technical details on the FAVAR estimation and data used, as well as empirical robustness checks, are left in the Technical Appendix.

2 Empirical Analysis

We use a factor augmented VAR (FAVAR) to estimate the response to monetary policy uncertainty shocks for the US economy over the period 1985:m1 to 2016:m6.[6] Relative to a small-scale VAR, the FAVAR offers three key advantages. First, it allows the inclusion of data on sector-specific entry and exit, thus capturing the relationship between sectors. Second, the FAVAR can easily handle mixed frequencies and missing data allowing us to use monthly data on variables related to monetary policy uncertainty together with industry-specific data that is only available at a

[6] The beginning of the sample period is justified by the beginning of the great moderation period and also by the first date available for the MPU index. The end of the sample period is instead simply justified by the last available observation for the series of daily conditional volatility (Carlston and Ochoa (2016)) we used to construct our instrument.

quarterly frequency. Finally, the use of a large data set makes it less likely that the model suffers from information insufficiency (see Forni and Gambetti (2014)).

The observation equation of the FAVAR model is defined as

$$\begin{pmatrix} Z_t \\ \tilde{X}_t \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \Lambda \end{pmatrix} \begin{pmatrix} Z_t \\ F_t \end{pmatrix} + \begin{pmatrix} 0 \\ v_t \end{pmatrix} \tag{1}$$

where Z_t is the monetary policy uncertainty index built by Husted et al. (2019). $\tilde{X}_t$ is a $M \times 1$ vector of variables that includes aggregate measures of macroeconomic and financial conditions provided by FRED-MD database (McCracken and Ng (2016)). $\tilde{X}_t$ also contains aggregate and sector-specific measures of firms' entry and exit provided by the Bureau Labor Statistics-BED database. Details of the data used are in the Technical Appendix. F_t denotes a $K \times 1$ vector of unobserved factors while Λ is a $M \times K$ matrix of factor loadings. Finally, v_t is a $M \times 1$ vector that holds the idiosyncratic components. We assume that each row of v_t follows an $AR(P)$ process:

$$v_{it} = \sum_{p=1}^{P} \rho_{ip} v_{it-p} + e_{it}, \tag{2}$$

$$e_{it} \tilde{} N(0, r_i), R = diag\left([r_1, r_2, .., r_M]\right) \tag{3}$$

where $i = 1, 2, .., M$.

Collecting the factors in the $N \times 1$ vector $Y_t = \begin{pmatrix} Z_t \\ F_t \end{pmatrix}$, the transition equation can be described as:

$$Y_t = BX_t + u_t, \tag{4}$$

$$u_t \tilde{} N(0, \Sigma) \tag{5}$$

where $X_t = [Y'_{t-1}, .., Y'_{t-P}, 1]'$ is $(NP + 1) \times 1$ vector of regressors in each equation and B denotes the $N \times (NP + 1)$ matrix of coefficients $B = [B_1, ..., B_P, c]$. The covariance matrix of the reduced form residuals u_t is given by Σ. Note that the structural shocks are defined as $\varepsilon_t = A_0^{-1} u_t$, where $\varepsilon_t \sim N(0, 1)$ and $A_0 A'_0 = \Sigma$.

2.1 Temporal Aggregation and Missing Data

Most of the data used in the FAVAR are collected at a monthly frequency. However, for some variables data are available only at a quarterly frequency. In the Technical Appendix, we specify all the series used and their frequency. In total, we consider 168 series of macroeconomic and financial variables for the U.S., economy. Among the series at the quarterly frequency, we use data on the real GDP, real consumption, real investment, total hours, and total factor productivity. Data on firms' entry and exit are available at a quarterly frequency as well but contain missing observations at the beginning of the sample period. Among the monthly series, the only ones containing missing observations at the end of the sample period are our measures of stock price and stock market return[7].

[7] The series of stock market return and stock price are taken from Caldara et al. (2016). For the stock price, we use the S&P Goldman-Sachs Commodity Index. We take this measure of stock price to address the possible issue of contamination of uncertainty shocks from commodity shocks. We tested the robustness of our findings by taking a different measure of stock price, that is the Standard & Poor 500 index, which is available up to the end of our sample period. We run the sensitivity analysis taking the logarithm and detrending the data as in Altig et al. (2020).

In particular for quarterly series (x_t), the observation equation is defined as:

$$\hat{x}_{jt} = \delta_j F_t + v_{jt} \tag{6}$$

where $\hat{x}_{jt}$ denotes unobserved monthly growth rates of the jth series in x_t and δ_j are the associated factor loadings. Over years where quarterly observations are available, we assume the following relationship between quarterly and monthly growth rates:

$$x_{jt}^{Q} = \sum_{j=0}^{2} \hat{x}_{jt} \tag{7}$$

In other words, the quarterly growth rates are assumed to be the sum of the unobserved monthly growth rates in that quarter. In detail, we treat $\hat{x}_{jt}$ as additional unobserved states and add a step in our MCMC algorithm to draw from their conditional posterior distribution.

2.2 Identification

We are interested in identifying the monetary policy uncertainty shock, that we denote ε_t^{MPU} and order first in the vector ε_t for convenience. We employ an external instrument approach to identify the structural shock of interest as in Stock and Watson (2008) and Mertens and Ravn (2013). Following Husted et al. (2019), our instrument is constructed by orthogonalizing a market measure of monetary policy uncertainty on FOMC meeting days to observed monetary policy surprises. In detail, our instrument is given by the regression residual of the daily conditional volatility of 1-month ahead options on 1-year interest rate swaps taken by Carlston and Ochoa (2016), over monetary policy surprises on FOMC meeting days. [8] We consider the same three measures of monetary policy surprises of Rogers et al. (2018), which cover three components: target rate, forward guidance, and asset purchase.[9] The estimation is carried out using data on FOMC meeting days from October 2008 to December 2015, when all monetary policy surprises are available.[10] The residual from that regression, m_t, can be interpreted as the measure of monetary policy volatility on FOMC meeting days that is unexplained by the change in the monetary policy itself. We take this daily measure as our instrument to identify the monetary policy uncertainty shock. The instrument is available for a shorter period than the rest of the data. This is similar to other papers identifying structural shocks using high frequency data as Gertler and Karadi (2015a) and Husted et al. (2019). While we use the full dataset spanning from 1985:m1 to 2016:m6 to estimate the FAVAR model in reduced

The sensitivity analysis, which confirms the findings of the benchmark FAVAR, is available from the authors upon request.

[8] Bauer et al. (2021) document the underlying drivers of monetary policy uncertainty using high-frequency data. They show that, on average, this uncertainty is mostly affected by FOMC announcements. Other events occurring during the FOMC meeting cycle, like macroeconomic news releases and speeches by FOMC participants, have only a minor impact on short-rate uncertainty.

[9] We thank Marcelo Ochoa and John Rogers for sharing the data on respectively, the swaptions volatility and the three measures of monetary policy surprises.

[10] One possible concern of using daily series as an instrument for high-frequency identification is that more economic announcements might be issued on the same days of the observations. If so, the information contained in the instrument could be distorted by economic releases that do not relate to the structural shock to be identified. The related literature on high-frequency identification of monetary policy shocks (Gurkaynak et al. (2004)) indicates the employment report releases issued at FOMC meeting days as one of the economic announcements that could imply a daily response in financial markets and, therefore, in the instrument that does not depend on FOMC decisions. To say that in our case, this concern is however minor. Over the sample period we take for our instrument only on one occasion, i.e. on 12^{th} December 2012, the FOMC meeting coincided with the release of an employment report.

form, we take the reduced form residuals and the instrument for the period in which the latter is available to identify the shock.

We assume that the instrument satisfies the *relevance* and *exogeneity* conditions:

$$E\left(m_t, \varepsilon_t^{MPU}\right) = \alpha, \alpha \neq 0 \tag{8}$$

$$E\left(m_t, \varepsilon_t^{-}\right) = 0 \tag{9}$$

That is, the instrument is assumed to be correlated with the monetary policy uncertainty shock ε_t^{MPU} and uncorrelated with the remaining shocks ε_t^{-}. The instrument is incorporated into the FAVAR model via the following equation

$$m_t = b\varepsilon_t^{MPU} + \sigma \hat{v}_t, \quad \hat{v}_t \tilde{} N(0,1) \tag{10}$$

2.3 Estimation and Specification

The FAVAR model is estimated using Bayesian methods. Following Bruns (2021) and Miescu and Mumtaz (2019), we extend the algorithm proposed by Caldara and Herbst (2019) for proxy VARs. The priors and the Gibbs sampling algorithm are described in detail in the Technical Appendix. Caldara and Herbst (2019) highlight that the prior for b and σ^2 are critical as they influence the reliability of the instrument. As in Mertens and Ravn (2013), we define the reliability statistic as the squared correlation between m_t and ε_t^{MPU}, or $\rho^2 = b^2/\left(b^2 + \sigma^2\right)$. In the baseline specification of the FAVAR, we set the priors for b and σ^2 implying that $\rho \approx 0.6$. In the sensitivity analysis, we check the robustness of the empirical findings by setting priors that reflect the belief that the instrument is less relevant.

We set to 6 the number of factors. The choice is based on the approach of Bernanke et al. (2005) who add additional factors until the estimated impulse response functions do not change with the addition of extra factors. In the Technical Appendix, we show that a higher number of factors delivers similar results to the baseline.

In order to keep the number of unobserved states at a manageable level, the lag lengths in equation (4) and (2) are fixed at 6 and 1, respectively.[11] The algorithm is run for 100,000 iterations with a burn-in of 75,000 iterations. Every fifth remaining draw is used to approximate the posterior distributions. The Technical Appendix presents evidence that is consistent with convergence.

2.4 Empirical Results

2.4.1 Monetary Policy Uncertainty Shocks

Figure 2 shows the impulse responses of selected macroeconomic and financial aggregate variables together with the responses of total private establishments' birth and deaths to the monetary policy uncertainty shock. Figure 2 reports dynamics responses up to the 2-year horizon of the growth rate of real GDP, real consumption, real investments, consumer price index, total factor productivity, total private establishments' births and deaths, non-farm business sector total hours, stock price. The series of the 1-year government bond rate is first-differentiated. Also, the responses of price inflation and nominal interest rate are annualized.

We study a one standard deviation shock that increases the MPU index by Husted et al. (2019)

[11] Our choice of 6 lags for the transition equation (4) is also motivated by the monthly frequency of the data. We tested the robustness of the estimates assuming 12 lags for the same equation. We report the impulse response functions of the alternative specification in the Technical Appendix.

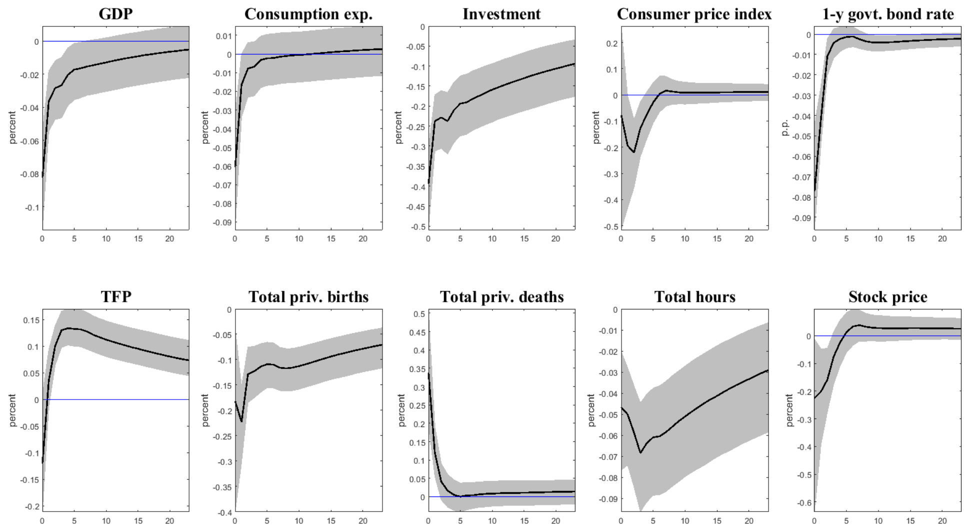

Figure 2: Impulse responses of a set of macroeconomic and financial variables to a one standard deviation monetary policy uncertainty shock. The solid line is for the median response. The shaded area represents the 68% error band.

by about 20%.[12] The GDP reduces by around 0.1%.[13] The negative response is stronger and long-lasting in investment. The impact is still significant at the 2-year horizon The decline in consumption is instead milder and less persistent. Not surprisingly, the persistence in the response in GDP is in between the two. Total hours are procyclical. The decline in hours is also long-lasting. Following the contraction in the economic activity, price inflation declines but the response is uncertain at the impact. The change in stock price is negative as well. For both consumer and stock price, the transmission of the shock is quite fast and absorbed after a few months. It is worth stressing that the macroeconomic effects of the monetary policy uncertainty shock resemble a negative demand shock. In response to the joint decline in output and inflation, the monetary policy becomes accommodative to foster the recovery. The short-run interest rate falls in response to the shock. Different from the rest of the variables shown in Figure 2, the response of the total factor productivity changes sign from the short to the medium horizon. The variation in the TFP is negative at the impact before turning positive from the third month ahead. Importantly, the overshooting of the response in the TFP is persistent and systematically different from zero even at the 2-year horizon. While the overall effect of the monetary policy uncertainty shock is recessionary, it brings about an improvement in TFP. Bloom (2009) obtains a similar result. In his paper, aggregate productivity growth is shown to fall after an uncertainty shock and then rebound in the medium-run. The response in TFP in our FAVAR shows a common behavior with Bloom (2009)'s findings. Importantly, our theoretical model proposed below produces a propagation mechanism that is consistent with the explanation given by Bloom (2009) about the TFP response. Namely,

[12] The magnitude is consistent with other uncertainty shocks estimated in the literature. For instance, Basu and Bundick (2017) estimate in a small VAR a one standard deviation uncertainty shock bringing about an increase in the VXO index of 15%.

[13] Remarkably, the drop in the real activity is close to the estimated impact Fernández-Villaverde et al. (2015) find for the GDP to a policy uncertainty shock.

the uncertainty shock triggers a reallocation from low to high productivity firms that ultimately drives the majority of productivity growth.

The monetary policy uncertainty shock has clear implications for firms' participation in the market. Establishments' births and deaths of the total private sector move in opposite directions. Our measure of firms' entry reduces in response to the shock whilst the measure of firms' exit increases. At the median, the surge in establishments' death is almost twice as large as the drop in establishments' births. Interestingly, the transmission of the shock is asymmetric. While births of new establishments are still decreasing at the 2-year horizon, deaths remain positive only for a few months after the shock. The impact on the net entry given by the difference between the percentage change in establishments' entry and exit, not shown in Figure 2, is negative and long-lasting.

The figures reporting the responses of establishments' births and deaths at the industry level are left in the Technical Appendix. It is worth mentioning that the signs of the responses of industry level data are similar to the aggregate responses: the response is negative for sector-specific firms' entry and positive for sector-specific firms' exit. As for the aggregates, the transmission is more persistent in establishments' births than in establishments' deaths. The magnitude of the impact at the industry level is however mixed. Among the good-producing industries, the response is larger on establishments' births and deaths in Construction and Manufacturing, while it is weaker in Natural Resources and Mining. Among the nine industries in the service-providing composite sector,[14] establishments' births drop more in Financial activities and Education and Health Services. Construction and Manufacturing are the goods-producing sectors that show the strongest reaction in establishments' deaths. In particular, the impact of deaths in Construction is more than twice as large as the aggregate. Information and Professional Services are the service-providing sectors that report the highest peaks in establishments' deaths.

In summary, the FAVAR estimates suggest four main conclusions. First, the monetary policy uncertainty shock is both recessionary and deflationary. All the responses of macroeconomic and financial variables we considered indicate that the economy is severely hit by such an innovation. In particular, the transmission of the monetary policy uncertainty shock is equivalent to that of a negative demand shock. Second, productivity in the economy is not affected negatively. Total factor productivity recovers immediately after the shock and improves further in the medium horizon. Third, the entry and exit of firms respond to the shock in the opposite directions. While the monetary policy shock reduces births of new establishments for several periods, establishments' deaths rise at the impact but the effect is short-lived. Taking jointly the two flows, the net entry declines and results as procyclical to output. Fourth, the empirical evidence on firm dynamics is robust both at the aggregate and industry level.

To better understand the role of firm dynamics in shaping the behavior of economic activity after a monetary policy uncertainty shock, in the next Section we run counterfactual exercises that switch off the effects on firms' entry and exit.

2.4.2 Contribution of Firms' Entry and Exit

The evidence provided by Section (2.4.1) indicates that the measures of firms' entry and exit are significantly affected by the monetary policy uncertainty shock. What is the role of firm dynamics in propagating this shock? To investigate the issue, we carry out a counterfactual exercise that switches off the transmission of the shock to firms' entry and exit, respectively. To be more precise, the counterfactual responses are calculated by solving for shocks in the transition equation of the FAVAR to impose the restrictions that the response of total establishments' birth in one case, and

[14] That is Wholesale, Retail, Transportation, Information, Financial, Professional Services, Education, Leisure, Other Services.

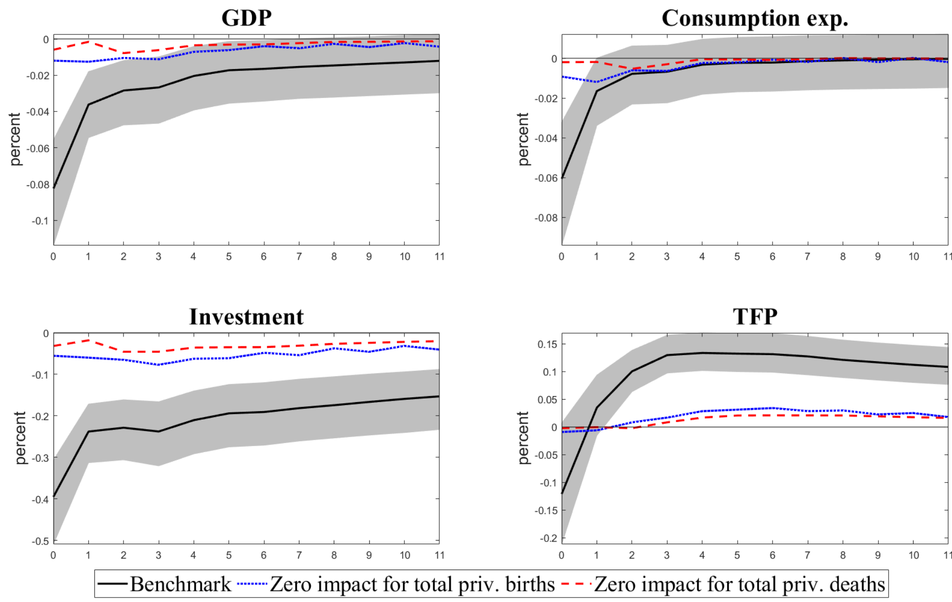

Figure 3: Impulse responses to a one standard deviation monetary policy uncertainty shock. The black solid line and shaded areas refer to the median and the 68% error band for the benchmark. The red dashed and dot-dashed lines refer to the median responses in the two counterfactual exercises.

of total establishments' exit in the other, equal zero over the entire horizon. These conditions reproduce the counterfactual scenario where monetary policy uncertainty does not affect firms' entry and exit at the aggregate level.[15] The panels in Figure 3 confirm the relevance of the firm dynamics channel in the transmission of monetary uncertainty shock. We consider the same identified monetary policy uncertainty shock of Section (2.4.1) and restrict the analysis to four variables: GDP, consumption, investment, and TFP. Taking the median among the impulse response functions and comparing the transmission in the baseline with the counterfactuals, we conclude that the impact of the shock is weaker in the latter. For GDP, consumption, and investment, the response is contained, especially under the counterfactual assumption that the monetary policy uncertainty shock does not affect total deaths. Furthermore, the overshooting of the total factor productivity is sizeably reduced in the counterfactual scenarios.

2.5 Exogeneity of the Identified Shock

Since structural shocks are not observable, it is not possible to test directly whether the proxy for the monetary uncertainty shock satisfies the exogeneity condition. We indirectly test this by verifying that our estimated monetary policy uncertainty shock is not significantly correlated with estimates of other shocks proposed by the literature. We consider a battery of previously identified shocks: TFP shocks, TFP-news shocks, investment-specific technology (IST) shocks, IST-news shocks, marginal efficiency of investment (MEI) shocks, monetary and fiscal shocks. The list of

[15] The counterfactual experiments are carried out by solving for additional shocks that are consistent with zero restrictions on the impulse responses of total establishments' entry and exit, respectively. This procedure is used in papers such as Mountford and Uhlig (2009) in the context of fiscal policy SVARs. As we do not change the coefficients of the FAVAR when running the counterfactual experiments, the Lucas critique does not apply directly. However, we acknowledge the caveat that the extra shocks needed to implement the restrictions are reduced form.

Shock	Source	Sample	ρ	$p-value$
TFP	Francis et al. (2014)	1985q3-2009q3	0.043	0.67
	Ben Zeev and Khan (2015)	1985q3-2012q1	−0.110	0.26
	Justiniano et al. (2011)	1985q3-2009q1	−0.050	0.63
TFP-news	Beaudry and Portier (2014), SR	1985q3-2015q3	−0.090	0.33
	Beaudry and Portier (2014), LR	1985q3-2015q3	−0.109	0.23
IST-news	Ben Zeev and Khan (2015)	1985q3-2012q1	−0.022	0.82
IST	Ben Zeev and Khan (2015)	1985q3-2012q1	0.074	0.45
	Justiniano et al. (2011)	1985q3-2009q1	0.180	0.08
MEI	Justiniano et al. (2011)	1985q3-2009q1	0.047	0.65
FISCAL	Ramey (2011)	1985q3-2014q2	0.095	0.31
	Fisher and Peters (2010)	1985q3-2008q4	0.058	0.58
MONETARY	Romer and Romer (2010)	1985m7-2007m12	0.015	0.81
	Gertler and Karadi (2015b)	1990m1-2016m6	−0.061	0.28
	Miranda-Agrippino (2016)	1990m2-2009m12	−0.034	0.60
	Miranda-Agrippino and Ricco (2021)	1991m1-2009m12	−0.075	0.26
	Rogers et al. (2018)	1990m1-2016m6	−0.026	0.64
	Jarociński and Karadi (2020)	1990m2-2016m6	−0.044	0.43
FINANCIAL	Gilchrist and Zakrajšek (2012)	1985q3-2011q1	−0.085	0.39
	TED Spread	1985m7-2016m6	−0.012	0.81
	Bassett et al. (2014)	1992q3-2011q2	−0.055	0.63

Table 1: Correlations between the FAVAR identified monetary policy uncertainty shock and other structural shocks in the literature, If the structural shock is available on quarterly frequency, then the monetary policy uncertainty shock is aggregate by summing across months. The TFP, TFP-news, IST, IST-news, MEI, and FISCAL shocks are collected from Ramey (2016). The monetary policy shocks are collected from the supplementary material of the papers cited. In particular, the updated series of Romer and Romer (2007)'s monetary shock is retrieved from Miranda-Agrippino's webpage. The FINANCIAL shocks are retrieved from Stock and Watson (2012).

all the shocks considered, their source, and the period overlapping with our series of the monetary uncertainty shock is reported in Table 1.[16] The same table reports the correlation coefficient and implied p-value. As shown in the table, in all the cases we cannot reject the null hypothesis of no correlation at the 5% significance level - that is none of these shocks is significantly correlated with our identified monetary policy uncertainty shock.[17]

[16] We collect quarterly series on TFP shocks, TFP-news shocks, IST shocks, IST-news shocks, MEI shocks from Ramey (2016). For the sake of comparability, we test the correlation with the shocks, which have in common at the least the 75% of the sample covered by our identified monetary policy uncertainty shock.

[17] Only the IST shock by Justiniano et al. (2011) is not far from being borderline case. One possibility is that our proxy for monetary uncertainty shock also detects some of the investment-specific shocks. An alternative possibility is that the identification strategy used in that paper fails to disentangle the contribution of their shock from that of monetary policy uncertainty. It is however worth noticing that this IST shock covers a relatively shorter sample than our shock. It ends in 2009q1. Thus, it is hard to give a definitive interpretation of the resulting correlation with our measure of monetary uncertainty.

2.6 Robustness

To validate the transmission of monetary policy shocks and test that this does not hinge upon the specification of the FAVAR, we carry out an extensive robustness analysis. A detailed description of the sensitivity analysis and its results is given in the Technical Appendix. Here, we summarize the main findings.

First, we assume a different number of factors in the model. We test the robustness of our results when the number of factors is set higher than in the baseline, that is to 7 and 8 factors respectively. We find evidence that responses in the FAVAR to the monetary policy uncertainty shock are not driven by the number of factors. The dynamics of the variables we investigate in Section 2.4 is fairly robust across the different FAVAR specifications we estimated.

Second, we tested the robustness of the estimates by assuming 12 lags for the transition equation (4). Although the model becomes less parsimonious in terms of parameters, estimated impulse response functions are close to those of the baseline FAVAR.

Third, we modify the prior concerning the variance of the error term in the instrument equation (10). As pointed out by Caldara and Herbst (2019), that prior is critical for the reliability of the instrument. We test the findings of the baseline FAVAR with a flatter prior, which reflects a weaker belief in the reliability of the instrument. We find that changing the priors barely affects the results. Though the responses are less precisely estimated as expected, their sign and magnitude remain consistent with the baseline FAVAR.

3 Theoretical Model

To investigate the transmission of the monetary policy uncertainty shock, we build and estimate a New Keynesian DSGE model with firm heterogeneity and firm dynamics. We first describe the building blocks of the key sectors of the DSGE model and consider how monetary policy uncertainty enters in this setup. Then, the estimated version of the model is used to calculate the impulse response functions to an unexpected increase in monetary uncertainty.

We label our model as *Baseline*. In brief, the Baseline model is a modified version of a standard DSGE medium-scale model. The main ingredients of this model and its microfoundations are well known in the literature (Christiano et al. (2005), Smets and Wouters (2007)), so the details are not discussed here. The model consists of a closed economy composed of four agents: households, firms, monetary authority, and fiscal authority. We assume sticky nominal wages and prices a là Rotemberg (1982), adjustment costs and capacity utilization for capital, external habit persistence. On top of that, we introduce firm heterogeneity and endogenous entry and exit dynamics in the intermediate sector. The full list of the equations characterizing the model is in the Technical Appendix. In what follows, a brief description of the behavior of the four agents is provided.

3.1 Households

Households consume a basket of differentiated retailer goods, C_t, and their consumption is characterized by external habits. They supply labor, L_t, to intermediate-good producing firms, they save in the form of new risk-free bonds, B_t, of physical capital, K_{t+1}, of portfolio shares of incumbent firms, x_t, and new entrants, N_t^E. The period utility of the household is defined over the Dixit-Stiglitz consumption bundle, C_t, and the labor bundle of services, L_t. It reads as follows:

$$U\left(C_t, L_t\right) = \frac{\left(C_t - h\overline{C}_{t-1}\right)^{1-\sigma_C}}{1-\sigma_C} \exp\left[\chi \frac{\left(\sigma_C - 1\right)\left(L_t\right)^{1+\sigma_L}}{1+\sigma_L}\right] \tag{11}$$

where h measures the degree of external habits in consumption, $\overline{C}_{t-1}$ is the last period aggregate consumption, σ_C defines the coefficient of the relative risk aversion that determines the constant intertemporal elasticity of substitution ($\frac{1}{\sigma_C}$), χ captures the relative weight assigned to labor and $\sigma_L > 0$ represents the inverse of the Frisch elasticity of the labor supply.

Households own physical capital stocks, K_t, and lease capital services, K_t^s, to firms, as in Smets and Wouters (2007). Capital services are related to the physical capital according to the following relationship:

$$K_t^s = u_t K_t \tag{12}$$

The household budget constraint is the following

$$\begin{aligned} & C_t + B_t + v_t\left(\tilde{z}_t\right) x_t + I_t + FEX_t N_t^E + T_t \leq \\ & w_t L_t + \left[r_t^K u_t - a(u_t)\right] K_t + \frac{1 + r_{t-1}}{1+\pi_t} B_{t-1} + \\ & + \left[(1-\eta_t)\left(v_t\left(\tilde{z}_t\right) + j_t\left(\tilde{z}_t\right)\right) + \eta_t l v_t\right]\left(x_{t-1} + N_{t-1}^E\right) \end{aligned} \tag{13}$$

Households enter in the period t earning the real gross income from labor, $w_t L_t$, the nominal return on bonds, $r_{t-1}B_{t-1}$, the real return of capital $\left[r_t^K u_t - a(u_t)\right] K_t$, where r_t^K is the real rental rate of capital, and $a(u_t)$ is the adjustment cost of variable capital utilization u_t. During the period t, households buy shares of incumbent firms, x_t and invest in new entrants N_t^E. In period $t+1$, with a probability $\left(1 - \eta_{t+1}\right)$ measuring the survival rate of firms, households earn from firms' value and profits. Defining $\tilde{z}$ as the average level of productivity, in $t+1$ households gain from the portfolio of firms the value $v_{t+1}\left(\tilde{z}_{t+1}\right)$ and profit $j_{t+1}\left(\tilde{z}_{t+1}\right)$. With a probability η_{t+1} measuring the exit rate of firms, households earn the liquidation value lv_{t+1}. T_t is a lump-sum transfer. The households spend all the earning to consume and save. The variable FEX_t captures the cost of entry paid by households for the new startup firms, which are defined, as in Casares et al. (2020), as a combination of constant and variable costs,

$$FEX_t \equiv f^E + ec_t \tag{14}$$

where f^E is the real cost of license fee paid to the fiscal authority to begin the production of a new variety, and ec_t measures congestion externalities for start-up firms:

$$ec_t = \Theta^e \left(\frac{N_t^E}{N_t}\right)^{\varsigma_e} \tag{15}$$

$\Theta^e > 0$ and $\varsigma_e > 1$.[18] Under congestion externality, entry is harder for new entrants as the greater the number of new entrants in any given period, the larger the entry costs faced by each potential entrant. As emphasized by Lewis (2009), this is a common feature in the firm dynamics literature and it is analogous to familiar quadratic adjustment costs for investments in physical capital since it serves the function of capturing the behavior of entry that responds gradually over time and not instantaneously to shocks, as observed in the data.

If a firm exits, a liquidation value is returned to households, which is a positive function of the fraction of the license fee paid at entry, f^E, and a negative function of exit congestion externalities, xc_t:

$$lv_t = (1-\tau) f^E - xc_t \tag{16}$$

where, as in Casares et al. (2020), $1-\tau$, with $0 < \tau < 1$, is the share of license fee returning to the

[18] Similar assumption on entry congestion extenalities can be found in Casares et al. (2020).

households and paid by the fiscal authority once a firm exits the market, while

$$xc_t = \Theta^x \left(\frac{N_t^X}{N_t} \right)^{\varsigma_x} \tag{17}$$

with $\Theta^x > 0$ and $\varsigma_x > 1$, represents exit congestion externalities.[19]

The law of motion of the firms follows the standard one-period time-to-build assumption as

$$N_t = (1 - \eta_t) \left(N_{t-1} + N_{t-1}^E \right) \ . \tag{18}$$

Hence, the stock of firms, N_t, is given by the sum of incumbent firms , $(1 - \eta_t) N_{t-1}$, and surviving new entrants, $(1 - \eta_t) N_{t-1}^E$. Firms' separation rate depends on an endogenous probability of defaulting, η_t, specified below. Both incumbent and new entrant firms are subject to the same endogenous exit probability. The exiting firms are thus given by

$$N_t^X = \eta_t \left(N_{t-1} + N_{t-1}^E \right) \ .$$

Households choose capital utilization and end up paying a quadratic cost for that utilization relative to its normalized steady state value, which is equal to 1,

$$a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2 \tag{19}$$

where γ_1 and γ_2 are the parameters governing the cost of utilization of capital.

Physical capital accumulates as follows:

$$K_{t+1} = \left(1 - \delta^K - S\left(\frac{I_t}{K_t} \right) \right) K_t + I_t \tag{20}$$

where δ^K is the depreciation rate, and $S\left(\frac{I_t}{K_t}\right)$ are capital adjustment costs defined as in Hayashi (1982), as:

$$S\left(\frac{I_t}{K_t} \right) = \frac{\phi_K}{2} \left(\frac{I_t}{K_t} - \delta^K \right)^2 \tag{21}$$

The implied first-order conditions of the household problem are listed in the Technical Appendix. They are the households' labor supply, the households' investment choice, the Euler equation for consumption, for physical capital, for shares holding, and the firm entry condition.

Households supply their homogenous labor to an intermediate labor union which differentiates the labor services and sets wages subject to Rotemberg (1982) adjustment costs. As for the FOCs of the household problem, the wage New-Keynesian Phillips curve (NKPC) resulting from the union problem is reported in the Technical Appendix.

3.2 Firms

As in Rossi (2019), the supply side of the economy consists of an intermediate and a retail sector. The intermediate sector is composed of a continuum of N_t intermediate firms that compete under monopolistic competition and flexible prices to sell the intermediate goods to a continuum of measure one of retailers. Each $k \in (0, 1)$ retailer buys intermediate goods from the intermediate sector

[19] As for the entry cost, it serves the function of capturing the dynamic behavior of exit over time as observed in the data. Though these costs help to capture the quantitative dynamics of entry and exit, the qualitative results of our model are not altered by the assumption of entry and exit congestion externalities.

and differentiates them with a technology that transforms the intermediate goods into an aggregate industry good, $Y_t^I(k)$, solving a minimum expenditure problem. Retailers sell the differentiated industry goods to households, competing with other retailers under monopolistic competition. They face Rotemberg (1982) adjustment costs so that, due to the monopolistic competition structure, the second optimization problem gives rise to the price NKPC.

3.2.1 Intermediate Sector

Each firm in the intermediate sector produces a differentiated good under monopolistic competition and flexible prices.[20] Firms are heterogeneous in terms of their specific productivity, which is drawn from a Pareto distribution. In this context, the production function of firm ι, with $\iota \in [1, N_t]$, is

$$y_{\iota,t} = z_{\iota,t} l_{\iota,t}^{1-\alpha} \left(k_{\iota,t}^s\right)^{\alpha} \tag{22}$$

where $l_{\iota,t}$ and $k_{\iota,t}^s$ are respectively, the amount of labor hours and capital services employed by firm ι, while $z_{\iota,t}$ is the firm-specific productivity, which is assumed to be Pareto distributed across firms, as in Ghironi and Melitz (2005). The coefficient α measures the elasticity of output with respect to capital.

This sector is characterized by endogenous firm dynamics. The timing characterizing the dynamics of firms is the following. At the beginning of the period, households invest in new firms until the entry condition is satisfied, that is until the average firms' value equals the entry costs,

$$v_t\left(\widetilde{z}\right) = FEX_t \tag{23}$$

Note that the value of the firm facing the average productivity corresponds to the stock price of the economy. The latter is so given by

$$v_t\left(\widetilde{z}_t\right) = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\left(1 - \eta_{t+1}\right) \left(v_{t+1}\left(\widetilde{z}_{t+1}\right) + j_{t+1}\left(\widetilde{z}_{t+1}\right)\right) + \eta_{t+1} l v_{t+1} \right) \right], \tag{24}$$

with λ_t as the marginal utility of consumption at time t, and $j_t\left(\widetilde{z}_t\right)$ as the current profits of the average firm.

Then, incumbent and last-period entrant firms draw their firm specific productivity from a Pareto distribution. The cumulative distribution function (CDF) of the Pareto implied for productivity $z_{\iota,t}$ is $G(z_{\iota,t}) = 1 - \left(\frac{z_{\min}}{z_{\iota,t}}\right)^{\xi}$, where $z_{\min}$ and ξ are scaling parameters of the Pareto distribution.[21] After drawing the idiosyncratic level of productivity, firms observe the aggregate shock and decide whether to produce or exit the market. Using this timing assumption, the decision of last-period entrants to exit the market is identical to the decision of incumbent firms. In particular, both new entrants and incumbent firms decide to produce as long as their specific productivity $z_{\iota,t}$ is above a cutoff level $\overline{z}_t$. The latter is the level of productivity that makes the sum of current and discounted future profits equal to the liquidation value, lv_t. Separated firms exit the market before starting the production. It follows that the average output and the average firms'

[20] In this model sticky prices are in the final sector and not in the intermediate good sectors, where the firm dynamism is modeled. This is for technical reasons. To satisfy the Melitz (2003) theorem of price aggregation markups should be the same across firms. Yet, the main results are not affected by the sticky-price assumption, since the stickiness in the final sector transmits to the intermediate sector.

[21] They represent respectively the lower bound and the shape parameter, which indexes the dispersion of productivity draws. As ξ increases, the dispersion decreases, and firm productivity levels are increasingly concentrated towards their lower bound $z_{\min}$.

productivity depend on the cut-off level of productivity in the economy, $\overline{z}_t$, which is endogenously determined through the following exit condition:

$$v_t(\bar{z}_t) = lv_t, \tag{25}$$

where the value of the firm with a productivity level that is equal to the marginal value $\overline{z}_t$ reads as

$$v_t(\bar{z}_t) = j_t(\bar{z}_t) + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(1-\eta_{t+1}\right)v_{t+1}(\bar{z}_{t+1})\right]. \tag{26}$$

Equation (26) states that the value of the marginal firm is given by its current profit $j_t(\bar{z}_t) = y_t(\bar{z}_t) - w_t l_{\bar{z},t} - r_t^K k_{\bar{z},t}^s$, with $w_t l_{\bar{z},t}$ the cost of labor and $r_t^K k_{\bar{z},t}^s$ the cost of capital services of the marginal firm.

The exit probability, $\eta_t = 1 - \left(\frac{z_{\min}}{\bar{z}_t}\right)^{\xi}$, is endogenously determined. As in Ghironi and Melitz (2005), the lower bound productivity level, $z_{\min}$, is low enough relative to the production costs, so that $\overline{z}_t$ is above $z_{\min}$. In each period, this ensures the existence of an endogenously determined number of exiting firms. The number of firms with productivity levels between $z_{\min}$ and the cutoff level $\overline{z}_t$ are separated and exit the market without producing.

3.2.2 Retailers

The retailer problem is split into two parts. First, each $k \in (0,1)$ retailer buys a fraction of the N_t intermediate goods produced by the N_t intermediate firms at prices $p_{\iota,t}$. Retailers bundle the goods into an aggregate industry good, $Y_t^I(k)$, minimizing their expenditure according to a CES technology $Y_t^I(k) = \left(\int_{N_t} y_{\iota,t}^{\frac{\theta_p-1}{\theta_p}} d\iota\right)^{\frac{\theta_p}{\theta_p-1}}$, with $\theta_p > 1$, as the elasticity of substitution among the intermediate goods varieties. Retailer's minimum expenditure problem implies the following demand function for the intermediate good ι:

$$y_{\iota,t} = \left(\frac{p_{\iota,t}}{P_t^I}\right)^{\theta_p} Y_t^I(k), \tag{27}$$

implying the intermediate sector price index as

$$P_t^I(k) = \left(\int_{N_t} p_{\iota,t}^{\theta_p-1} d\iota\right)^{\frac{1}{\theta_p-1}}.$$

Second, each k retailer competes with the others under monopolistic competition to sell its bundle, $Y_t^I(k)$, to the household at the price $P_t^R(k)$, which is a markup over the intermediate sector price index, $P_t^I(k)$. Retailers adjust prices according to the Rotemberg (1982)'s model. The retailer's optimal price decision rule implies the following standard NKPC:

$$1 = \frac{\theta_p}{\theta_p-1}\rho_t^I - \frac{\phi_p}{\theta_p-1}(\pi_t-1)\pi_t + \frac{\phi_p}{2}(\pi_t-1)^2 + \frac{\phi_p}{\theta_p-1}E_t\left\{\Lambda_{t,t+1}(\pi_{t+1}-1)\pi_{t+1}\frac{Y_{t+1}}{Y_t}\right\} \tag{28}$$

with ϕ_p as the adjustment price parameter, and ρ_t^I as the relative price $\frac{P_t^I(k)}{P_t}$. By symmetry among the retailers, it holds $Y^R(k) = Y_t$ and $P^R(k) = P_t$. Hence, $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate.

3.3 Monetary and Fiscal Authority

Monetary Authority

To close the model we specify an equation for the behavior of the Central Bank. We simply assume that the monetary authority sets the nominal net interest rate i_t following a standard Taylor-type rule given by

$$\log\left(\frac{1+i_t}{1+i}\right) = \phi_R \log\left(\frac{1+i_{t-1}}{1+i}\right) + (1-\phi_R)\left(\phi_\pi \log\left(\frac{\pi_t}{\pi}\right) + \phi_{dy}\log\left(\frac{y_t}{y_{t-1}}\right)\right) + \varepsilon_{R,t}, \qquad (29)$$

where ϕ_π and ϕ_{dy} are the elasticities of the nominal interest rate with respect to the deviation of the inflation from their long-run target and to the growth rate of output. The parameter ϕ_R is the interest rate smoothing parameter. We model the monetary uncertainty shocks by using the stochastic volatility approach proposed by Mumtaz and Zanetti (2013) and Born and Pfeifer (2014), that is by assuming time-varying volatility of the innovation to the monetary shock. Specifically, the policy uncertainty shock enters into the economy through the monetary shock, $\varepsilon_{R,t}$, that follows an AR(1) process,

$$\varepsilon_{R,t} = \rho_R \varepsilon_{R,t-1} + e^{\sigma_{R,t}} u_{\varepsilon,t} \qquad (30)$$

with

$$\sigma_{R,t} = (1-\rho_\sigma)\,\sigma_R + \rho_\sigma \sigma_{R,t-1} + u_{\sigma,t} \qquad (31)$$

where $u_{\varepsilon,t}$ is the Gaussian innovation to the monetary shock, i.e. the *level* innovation, while $u_{\sigma,t}$ is the Gaussian innovation to the standard deviation, $\sigma_{R,t}$, of the monetary shock, i.e. the *volatility* innovation. The steady-state value of monetary volatility is given by σ_R. A volatility innovation thus increases uncertainty about the monetary policy level shock.[22]

Fiscal Authority

The fiscal authority runs the following balanced budget:

$$T_t = f^E N_t^E - (1-\tau)\, f^E N_t^X$$

where T_t are lumps-sum transfers/taxes to the households, $f^E N_t^E$ are the revenues obtained from households in form of administrative fees for opening new startups, $(1-\tau)\, f^E N_t^X$ is the expenditure in form of liquidation value paid to households as firms exit the market.

3.4 Aggregation and Market Clearings

The economy aggregate output is implied by the following

$$Y_t = N_t^{\frac{1}{\theta_p - 1}} \widetilde{z}_t \left(L_t\right)^{1-\alpha} \left(K_t^s\right)^\alpha \qquad (32)$$

while the resource constraint of the economy is given by,

$$Y_t = C_t + I_t + a\left(u\right) K_t + N_t^E ec_t + N_t^X xc_t + PAC_t + WAC_t \qquad (33)$$

where

$$PAC_t = \frac{\phi_p}{2}\left(\pi_t - 1\right)^2 Y_t \qquad (34)$$

[22] Notice that we tested our model specifying the stochastic processes in levels as in Basu and Bundick (2017), where the volatility $\sigma_{R,t}$ does not impact the average value of level shock. However, the transmission of the uncertainty shock remains fully consistent with the benchmark specification.

and

$$WAC_t = \frac{\phi_w}{2}\left(\frac{w_t}{w_{t-1}}\pi_t - 1\right)^2 Y_t \quad (35)$$

are respectively the price and wage adjustment costs.

4 Model Estimation and Dynamics

In this Section, we describe the dynamics of our Baseline model conditional on a monetary policy uncertainty shock. Importantly, to understand better the role played by firm dynamics we compare the dynamics of the Baseline with that of a standard medium-scale model without firm dynamics, labeled as *No Firms*. We set the parameters of the models as follows. A set of parameters is fixed a priori and to the same value for both Baseline and No Firms. The remaining parameters are is estimated in each models using a limited information impulse response matching techniques in the spirit of Christiano et al. (2005), Basu and Bundick (2017), Mumtaz and Theodoridis (2019). Namely, these parameters are estimated using the FAVAR-implied impulse response functions of the growth rate of real GDP, real consumption, real investment, consumer price index, and of the yield of U.S. Treasury securities at 1-year constant maturity as data counterpart. With the estimated parameters in hand, we simulate the models and calculate the dynamic responses of the variables to an unexpected increase in monetary uncertainty.

4.1 Parameter Estimation and Calibration

Similar to Mumtaz and Theodoridis (2019), the values of a set of parameters are decided before the model estimation. For these parameters, we keep fixed the same calibration for Baseline and No Firms model. In what follows, we first report the description of the calibrated parameters. Then, we discuss the estimated parameters.

Calibrated Parameters The time horizon considered in the calibration is monthly. The discount factor, β, is so set at 0.9967, corresponding to an annualized real interest rate of about 4%. The coefficient of the relative risk aversion, σ_C, is set to 1.5, while the elasticity of labor supply, σ_L, to 5. The habits persistence parameter h is set to 0.6. All values of the parameters in the utility function lie within admissible intervals of estimates in the literature (Smets and Wouters (2007), Christiano et al. (2005)). The labor disutility parameter χ is obtained from the steady state relationships. The capital-income share α is set to 0.33, whereas the depreciation rate of the physical capital, δ_k, is set to 0.0067, which is equivalent to around 2% every quarter. Once β and δ_k are calibrated, the parameter γ_1 is determined by the equations in the steady state. The parameter measuring the elasticity of the capital utilization adjustment cost function, γ_2, is set to 0.54 as in Smets and Wouters (2007). The output in the steady state is normalized to 1. The steady state value of the exit probability η is set to match the U.S. quarterly establishments' death ratio, which is at around 3% for the period considered in the FAVAR analysis. The parameter of the elasticity of substitution among intermediate goods, θ_p, is set equal to 4.3, corresponding to a steady state price markup of around 30%. Though this value is in line with the literature on firm dynamics (Ghironi and Melitz (2005), Bilbiie et al. (2012)), we test the robustness of the results at a different level of price markup. We set the markup in the labor market as the baseline for the good market, so that the elasticity of substitution among labor types θ_w is fixed to 4.3. The shape parameter of the Pareto distribution ξ is set equal to 6.51 to satisfy the steady state value of the exit rate. This value also guarantees that the condition for well-behaved average productivity, i.e. $\xi > \theta_p - 1$, is satisfied.

The lower bound of productivity distribution, $z_{\min}$, is equal to 1. The variable components of entry and exit costs, ec and xc, are set, respectively, to 1.6% and 1.2% of the GDP in the steady state. The elasticities of entry and exit congestion externalities, ς_e and ς_x, are set to 2 and 1. Both the variable components of sunk costs and the congestion externalities are set slightly higher for entry than for exit, which is consistent with the estimates in Casares et al. (2020). Once ec, xc, ς_e, ς_x are calibrated, the remaining constant component of the entry cost, f^E, and the parameters Θ^e and Θ^x are endogenously determined.[23] The share of the fixed entry cost of the exiting firms rebated to the households is fixed to 25% so the parameter τ is set to 0.75.

Estimated Parameters We estimate all the parameters of the exogenous processes. These include the persistence of the monetary shock ρ_R, the persistence of the monetary uncertainty shock ρ_σ, and the steady state value of the monetary shock volatility, σ_R. Parameters describing the degree of price and wage adjustment costs, that is ϕ_P and ϕ_W are also estimated. The same is true for the parameter of the investment adjustment cost, ϕ_k. Finally, we estimate the coefficients of the Taylor rule ϕ_R, ϕ_π and ϕ_{dy}. The set of parameters to be estimated $(\sigma_R, \rho_R, \rho_\sigma, \phi_P, \phi_W, \phi_k, \phi_R, \phi_\pi, \phi_{dy})$ are thus selected to match the FAVAR-implied responses to the identified monetary policy uncertainty shock.

Values of the estimated parameters for both models are reported in the Technical Appendix. The estimated steady state standard deviation of the monetary policy uncertainty shock, σ_R, does not vary substantially across the models. However, while the Baseline model requires a moderate persistence in the Taylor rule, ϕ_R, and almost zero persistence of the monetary policy shock, ρ_R, the No Firms model implies almost the opposite. The Baseline model requires a substantially lower degree of price and wage rigidities, that is lower values of ϕ_P and ϕ_W, to match FAVAR-implied responses. This result seems of particular interest and is consistent with the recent findings by Bilbiie and Melitz (2020). These authors show that a model with endogenous entry-exit radically changes the consequences of nominal rigidities introducing an aggregate demand amplification when approximated to an order higher than one. In other words, frictional entry-exit introduces an endogenous form of price stickiness that amplifies the real effect of the shock. Our estimation shows that the aggregate demand amplification channel survives in response to a monetary policy uncertainty shock and that the endogenous stickiness implied by frictional entry-exit requires a lower degree of price and wage rigidities. Estimates for both models deliver a similar value for the investment adjustment cost, ϕ_k. About the remaining parameters in the Taylor rule, the Baseline and No Firms model call for a relatively high inflation feedback parameter ϕ_π and low value of output growth feedback parameter ϕ_{dy} In particular, the high inflation feedback parameter guarantees the uniqueness of the equilibrium in both models.

We also test the Baseline and No Firms model with an alternative calibration keeping fixed the coefficients of the Taylor rule ϕ_R, ϕ_π, ϕ_{dy} to 0.5, 2.5, 0.05 respectively. For the alternative calibration, we choose to estimate the vector of parameters $(\sigma_R, \rho_R, \rho_\sigma, \phi_P, \phi_W, \phi_k)$ but exclude the FAVAR-implied response of the short-run nominal interest rate from the data counterpart. Estimates for these parameters and the corresponding impulse response functions analysis are reported in the Technical Appendix.

4.2 IRFs to Monetary Policy Uncertainty Shocks

The rest of this Section documents the transmission of the monetary policy uncertainty shock in the DSGE models. We compute the impulse responses in deviation from the stochastic steady state as

[23] Though entry and exit adjustment costs help to capture the quantitative dynamics of entry and exit, we tested that the qualitative results of our model are not altered by the assumption of entry and exit congestion externalities.

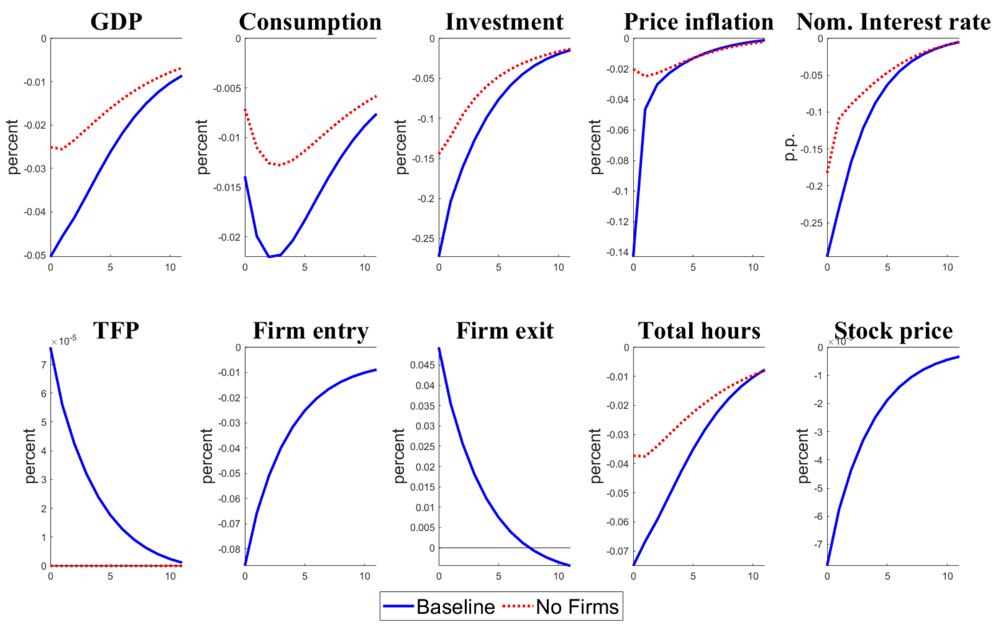

Figure 4: DSGE impulse responses to a one standard deviation monetary policy uncertainty shock. Baseline (blue line) versus No Firms (red dotted line). Annualized impact for consumer price inflation and nominal interest rate.

suggested by Fernández-Villaverde et al. (2015). We show the impulse responses for Baseline and No Firms model when structural parameters are calibrated as described in Section 4.1. The comparison between the models allows us to investigate the relevance of firm dynamics and firm heterogeneity in explaining the propagation of the shock. Recall that in No Firms, only the intensive margin of the investment, namely the one in physical capital, is allowed to respond, while the extensive margin, namely the investment in new firms, is neglected.

Figure 4 shows the responses to the monetary policy uncertainty shock for Baseline and No Firms model.[24]. In particular, the panels on the first row of Figure 4 show the implied dynamics of the variables that we use in the matching with the FAVAR, while the second row reports the dynamics of the other series that are not used in the matching.

In both specifications, a monetary policy uncertainty shock generates a positive comovement in output, consumption, investment in physical capital, and hours worked. The increase in monetary volatility is followed by a slump in all four variables. As emphasized by Basu and Bundick (2017), the result is standard in macroeconomic models with nominal rigidities, where the fall of the aggregate demand is sufficiently large to make both consumption and investment in capital as declining in response to the heightened volatility. However, our Baseline model also embeds the extensive margin of investments, namely firm entry and exit. Because of the endogenous responses of entry and exit, the impact is larger in the Baseline model. A one standard deviation shock in the volatility of the monetary shock depresses the GDP. The recession is larger and lasts more in Baseline than in No Firms. Differences in the dynamics of the two models widen for the nominal variables. Also for the latter, the impact is relatively stronger in the Baseline model. Unsurprisingly,

[24]To be consistent with the data in the FAVAR model, we comment on the impulse responses we obtain for DSGE models for aggregate variables that are depurated by the love of variety, $N_t^{\frac{1}{\theta_p - 1}}$.

given the heavier impact on output and inflation, the short-term interest rate falls more in the Baseline model. The monetary policy is indeed more accommodative to mitigate the effects of the heavier recession.

By construction, the response of the TFP is muted in the No Firms model. In contrast, in the Baseline model, aggregate productivity responds positively to the monetary policy uncertainty shock. The reason lies in the selection effect in the productive sector. As a consequence of the increased threshold $\overline{z}_t$, the less productive firms are pushed out of the market, and aggregate productivity increases after the shock. Remarkably, this selection effect is close to Bloom (2009). The author explains the rebound in productivity after the uncertainty shock with the reallocation from low to high productivity firms that drives the majority of productivity growth in the model. It is worth stressing that in our FAVAR, the TFP shows a negative response only at the impact of the shock. Thereafter, the TFP overshoots its long-run trend and remains persistently positive. The differences at a very short horizon can be justified by the fact that the creative destruction mechanism we emphasize in our model is only one of the possible mechanisms affecting the TFP. Another possible channel might be the dynamics of the labor market and in particular, that of hours worked and unemployment. During a recession, unemployment increases with lags. It follows that total hours worked are further affected by delays. The same occurs for the stock of capital. While output reacts immediately, sluggish adjustments in the productive factors can justify the initial reduction of the TFP. However, as soon as unemployment increases and firms with lower productivity are pushed out of the market, the TFP increases and remains positive when the shock transmits to the rest of the economy. Ultimately, in the medium run, the response of the aggregate productivity in the Baseline model is consistent with the one obtained by the FAVAR. This corroborates our claim that the DSGE specification that encompasses both heterogeneous productivity at the firm level and endogenous entry and exit is the one that fits better the empirical evidence.

Focusing on the responses of entry and exit of firms, it is worth noticing that the Baseline model closely replicates the evidence of the FAVAR indicating that the two flows react in the opposite way to a monetary policy uncertainty shock. Further, in the Baseline model, the decline in the entry is driven by the reduction in the firm value, namely the stock price in the model. This matches the evidence from the FAVAR model. From equation (24), the firm value in our model is given by the present discounted value of the stream of expected future profits. After the monetary policy uncertainty shock, firm profits decline and the minimum level of productivity, $\overline{z}_t$, which guarantees the market participation, increases. The exit probability, which depends on the minimum level of productivity, rises as well. This has implications for entry and exit. On the entry side, the increased exit probability affects the overall stochastic discount factor at which future firm profits are discounted. This dampens the average firm value and makes the fall in entry large.

Robustness checks In the Technical Appendix, we test the robustness of the DSGE-based estimates.

We find that for the Baseline model the responses of all the variables we match lie in the 68% credible intervals of the FAVAR except the nominal interest rate. In the alternative specification, the model-implied responses of GDP, consumption, and investment lie outside the credible intervals of the FAVAR. We take this evidence as further support that the Baseline model outperforms the No firms model. Although there is an overreaction of the nominal interest rate with respect to the FAVAR, this is common to both models and might be explained with the high values for the estimated parameter, ϕ_π, which requires a strong reaction of the interest rate to the change in inflation. When we calibrate the Taylor rule parameters using the same values in Baseline and

No Firms and repeat the estimation of the models by removing the nominal interest rate among the impulse response functions to be matched, the main conclusions are however unaffected. The effects of the monetary policy uncertainty shocks are amplified in the Baseline model. The Technical Appendix reports the DSGE-implied impulse response functions for the alternative calibration.

Second, we check the robustness of our findings by using the same calibration as in the main text but with different values for i) the elasticity of substitution in the goods market, ii) the degree of rigidity in price adjustment, and iii) the persistence of the monetary level shock. The different calibration barely affects the transmission of the monetary policy uncertainty shock in the Baseline. However, we show that a lower elasticity of substitution in the goods market, higher price rigidities, and a more persistent monetary policy shock all bring about a more severe and long-lasting impact of the monetary policy uncertainty shock.

5 Conclusion

In this paper, we use a FAVAR model to show that a shock that increases uncertainty around monetary policy is associated with a drop in output and inflation, declining stock prices, lower entry of new firms, and increased firms' exit. Further, the utilization-adjusted TFP increases persistently in the medium-run. We show that the contribution of entry and exit is critical to explain differences in monetary policy level and volatility shocks. To rationalize these results, we provide and estimate a medium-scale DSGE model with heterogeneous firms and endogenous firm dynamics. Unlike the standard DSGE model, the extended model can match the response for firms' entry and exit to the monetary policy uncertainty shock. Also, the dynamics of the stock price is consistent with the FAVAR. Our model suggests that the larger impact on real activity is driven by the propagation of the shock through firm dynamics. Moreover, thanks to the presence of firm heterogeneity and endogenous firm defaulting, a monetary uncertainty shock improves resource allocation in the model by driving out less productive producers and increasing the TFP as in the FAVAR.

A promising extension of our contribution concerns the comparison of the effects of first- and second-moment monetary policy shocks once the firm dynamics channel is at work. Also, a closer inspection of the effects of monetary policy uncertainty shocks on the equity return would be valuable to understand the impact on the firm profitability. We leave both investigations to future research.

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