Endogenous Uncertainty and the Macroeconomic Impact of Shocks to Inflation Expectations*

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Abstract

A shock that increases short-term inflation expectations has negative macroeconomic effects, increasing inflation and decreasing output. The third-order solution of a rich DSGE model with firm dynamics shows that the endogenous increase in uncertainty is key for both amplifying the transmission mechanism and providing robust sign restrictions to identify the inflation expectations shock in an empirical VAR. The model, estimated using limited information impulse response matching techniques, shows the importance of endogenous uncertainty and firms dynamics for the transmission mechanism of an inflation expectation shock. Furthermore, shocks that increase inflation expectations have stronger effects than shocks that reduce inflation expectations.

Keywords: Endogenous Uncertainty, VAR, Inflation Expectations, Firm Dynamics.

JEL codes: C5, E3, E5, E52

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1 Introduction

What is the macroeconomic impact of a shock that increases short-term inflation expectations? It is somewhat surprising that, to the best of our knowledge, there are virtually no results in the literature that answer this question.

It is surprising given the prominent role of expectations in theoretical models and policy discussions. The literature, indeed, shows that exogenous changes in inflation expectation do affect fundamental economic decisions by agents, as households spending (e.g., Coibion et al., 2022) and firms investment, employment and pricing decisions (e.g., Coibion et al., 2019). The recent and thriving literature on inflation expectations provides, using survey data, a host of seminal results on the topic (see Coibion et al., 2022, for a survey). This literature naturally concentrates on explaining the survey micro data, understanding the formation, the determinants and the heterogeneity of inflation expectations. We take here a different and complementary approach, that is, a macroeconomic perspective. While it is obviously important to understand how inflation expectations are formed by reacting endogenously to the macroeconomic environment, we want to assess what are the macroeconomic effects of an exogenous change of short-term inflation expectations. Surveying the literature D'Acunto et al. (2022) conclude that agents' expectations are biased upwards and volatile in the time series, which suggests that inflation expectations might be subject to shocks that exogenously explain such volatility.

Moreover, it is surprising because 'expectational shocks' have been the subject of extensive recent work in macroeconomics, where exogenous changes in expectations are assumed to drive economic fluctuations, through belief, sentiment, confidence or news shocks.[1] This literature investigates, both empirically and theoretically, how news about future TFP (e.g., Beaudry and Portier, 2006, 2014; Barsky and Sims, 2011, 2012) or exogenous waves of optimism and pessimism due to sentiment (e.g., Benhabib et al., 2015; Angeletos et al., 2018) affect business cycle fluctuations. Despite not derived from explicit microfoundations, our exogenous shock to short-term inflation expectations falls in this category. Angeletos et al. (2018) introduce a shock to short-run expectations to real variables, as a reduced-form shock to capture a sentiment shock due to higher-order beliefs. They stress that their short-run expectational shock is different from optimism/pessimism that in the literature on news shock usually applies to expected TFP increases in the distant future. Similarly, in our case, our expectational shock to short-term inflation expectations differs from the ones so far analyzed in literature on 'de-anchoring', which focuses to shocks to long-term inflation expectations (e.g., Clark

[1] *"There is a widespread belief that changes in expectations may be an important independent driver of economic fluctuations."* This is the opening sentence in the abstract of the influential paper by Beaudry and Portier (2014).

and Davig, 2011; Diegel and Nautz, 2021; Neri, 2021) or to the inflation target of the central bank (which, in equilibrium would coincide with long-term inflation expectations in most models; e.g., Ireland, 2007; Cogley et al., 2010; Haque, 2019).

Through the lens of a rich DSGE model with firm dynamics, this paper answers the question at the start about the macroeconomic impact of a shock that increases short-term inflation expectations, showing that such a shock has negative macroeconomic effects, similar to a standard supply shock: it increases inflation and decreases output.

One of the main problems in the literature on expectational shocks relates to their identification.[2] We face a similar challenge to disentangle the inflation expectation shock from a standard supply shock, that has similar effects on macroeconomic variables. Hence, another contribution of the paper is to propose a novel identification mechanism based on endogenous uncertainty, since the model implies a positive response of real GDP uncertainty to a shock to a positive inflation expectation shock - and a negative one in response to a supply shock. In this respect, this paper is the first attempt to propose an identification strategy of a level-shock, i.e., a shock to the level of inflation expectations, that relies on the response of second-order variables, i.e., the endogenous response of uncertainty to this shock.

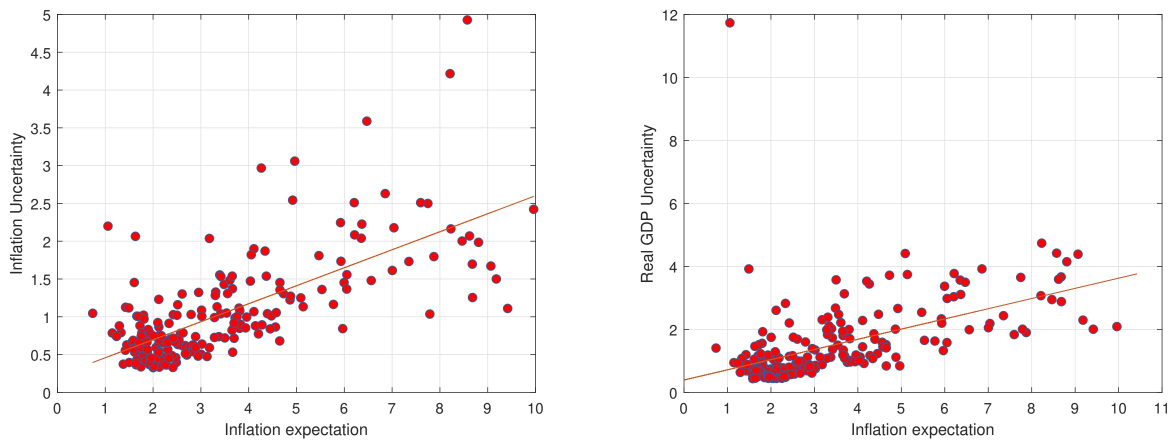

Figure 1: **Left**: Mean one-quarter ahead inflation expectations of the SPF and inflation uncertainty from the SPF, i.e., standard deviation of individual point forecasts on GDP price index growth rate. **Right**: Mean one-quarter ahead inflation expectations of the SPF and GDP uncertainty from the SPF, i.e., standard deviation of individual point forecasts on real GDP growth rate.

Figure 1 provides suggestive evidence that our mechanism can have some grip in the data. It shows a positive relationship between inflation expectations and inflation uncertainty in U.S. data, where the former is the quarterly mean forecasts of the Service of Professional Forecasters (SPF) and the latter is

[2]Very recently, for example, Levchenko and Pandalai-Nayar (2018) propose a novel identification scheme to distinguish among surprise TFP, news of future TFP, and sentiment shocks, Nam and Wang (2019) one to identified optimism and pessimism shocks and Chahrour and Jurado (2021) another one to disentangle technological and expectational disturbances.

the standard deviation of their forecasts.[3] Higher average levels of short-term inflation expectations are thus linked to higher dispersion of these levels, suggesting a possible endogenous relationship between levels and variance. Figure 1 shows also a positive relationship between inflation expectations and real GDP forecasts dispersion, measured as the standard deviations of individual point forecasts on real GDP, from SPF. Our VAR analysis exhibits these positive relationships conditionally to a short-run inflation expectation shock.

Concretely, the paper proceeds in four steps. In the first step, we use the third-order solution of a medium-scale DSGE model characterized by endogenous firm entry/exit to investigate the macroeconomic effects of a shock to short-term inflation expectations. In the theoretical model, the equity price is endogenous and strongly related to firm endogenous entry/exit decisions. The model shows that a shock that increases inflation expectations is inflationary and determines a reduction in output, consumption, and investments. Thus, the IRFs resembles the one of a standard supply shock: inflationary and recessionary and implies an increase in the dividend-to-price ratio. Further, we define three endogenous measures of uncertainty, i.e., inflation uncertainty, output uncertainty, and equity return uncertainty, as the standard deviation of the one period ahead agents' forecasts. The third-order solution of the model shows that this shock is followed by an endogenous increase in output uncertainty, equity return uncertainty, and inflation uncertainty. These measures are instead by construction silent in a first-order solution of the model. To assess the importance of the uncertainty channel, the model IRFs obtained with the third-order solution of the model are compared with the ones obtained with the first-order solution of the model. This comparison shows that the uncertainty channel is not negligible in the transmission of an inflation expectations shock. The increased uncertainty brings about a reduction in the economic activity and firms' net entry that contribute to further reduce output.

In the second step, we use the theoretical model to provide an identification strategy to disentangle an inflation expectations shock from a more standard supply shock. The identification strategy derives from simulating the theoretical model to determine robust sign restrictions to impose in the empirical VAR, in the spirit of Canova and Paustian (2011). The model simulations provide the main identification assumption to distinguish between an inflation expectation shock and a supply shock. Both shocks are inflationary and recessionary, but they differ for the response of the expected dividend-price

[3] We are aware that a more precise measure of uncertainty would be the standard deviation taken from the probability distribution of a single forecaster. The SPF provides density forecasts for GDP deflator and real GDP. However, these data have several rounding and time-inconsistency issues making estimations of uncertainty not reliable. Therefore, we assume that the distribution across different forecasters is a good proxy of the distribution of the representative forecaster.

ratio and output uncertainty, which increase in response to an inflation expectation shock, while it decrease in response to a negative supply shock. Our identification strategy is then based on these different signs of the responses of the expected dividend-price ratio and output uncertainty. Furthermore, following Antolín-Díaz and Rubio-Ramírez (2018), we add a narrative sign restriction to better identify the inflation expectations shock, assuming that the nomination of Volcker caused a negative shock on inflation expectations. Thus, the narrative restriction that in Q3/1979 the shock to inflation expectations has been negative is imposed on the VAR model.

In the third step, we estimate a VAR on U.S. data, featuring three empirical measures of uncertainty: i) inflation uncertainty, measured using the standard deviation of one period ahead forecast of US GDP deflator; ii) macroeconomics uncertainty, measured using the standard deviation of the one period ahead forecast of real GDP taken by professional forecasters; iii) financial uncertainty, measured by the VXO.[4] The VAR analysis suggests that a shock that increases inflation expectations by one standard deviation is associated with an increase in all the three measures of uncertainty considered in the VAR, that is inflation, output, and financial uncertainty, even if only the response of output uncertainty is imposed. This is consistent with the theoretical model, where the endogenous increase in uncertainty of these variables contributes to amplify the negative response of output to an inflation expectation shock. Moreover, the VAR response of inflation (which is left unconstrained in the identification) is consistent with the model prediction.

In the final step, the third-order solution of the model is used to estimate a set of the model parameters using limited information impulse response (IRFs) matching techniques as in Christiano et al. (2005), Christiano et al. (2010), Mumtaz and Theodoridis (2020) and Fasani et al. (2022) among others. These parameters are first estimated using the model-IRFs generated by the third order solution of the model. Then, to empirically capture the role played by uncertainty, the same matching exercise is repeated using the model-IRFs obtained from the first order solution of the theoretical model, and thus without the contribution coming from endogenous uncertainty. The estimation done using the third-order approximation of the model implies IRFs that are closer to the empirical counterpart and it is preferred by the data, in terms of value function. This provides additional validation of the importance of uncertainty in the data and in the transmission mechanism of the inflation expectation shock. Comparing the model with and without firm dynamics, we find that the model with firm dynamics is key to obtain the amplification of the recession. Our analysis

[4] These measures have the advantage of measuring uncertainty using the standard deviation of the forecast and not of the forecast error, thus being in line with the typical definition of uncertainty.

suggests that firms dynamics is an essential component of our modeling strategy, and, indeed, the same analysis in a model without firms dynamics worsen the empirical fit of the model and is not consistent with the VAR IRFs of the uncertainty measures.

Last, but not least, we show that the third-order solution of the model implies the existence of asymmetries in the transmission of shocks to inflation expectations. Specifically, shocks that increase inflation expectations have stronger effects than shocks that decrease inflation expectations. To capture the empirical implications of having asymmetric effects of the shock, the final section of the paper uses alternatively the model-IRFs of the third-order solution of the model obtained by hitting the economy with a shock that increases inflation expectations (positive shock) and the ones obtained by a shock that reduces inflation expectations (negative shock) to match the (linear) VAR-IRFs. The two cases deliver different estimates, which must be due to a an asymmetric effect of the shock in the non-linear model, given that the VAR-IRFs are by construction symmetric. Then, as a natural step-ahead in the investigation of the asymmetric effect of the shock, we test asymmetric effects of inflation expectations shocks in the data through local projection analysis. We retrieve the structural shock estimated in our linear VAR model and project the estimated negative and positive shock from the VAR to our main macroeconomic variables of interest. We show that positive shocks to inflation expectations, that is shocks that increase the expectations, imply a stronger reaction of GDP, inflation, the dividend-to-price ratio and output uncertainty. In other words, while positive shock imply a strong and long-lasting recession, negative shocks - shocks that reduces inflation expectations - imply a substantially mild reaction of these variables.

Our paper is related to works that stress the endogenous response of uncertainty to aggregate shock. Ludvigson et al. (2020) were the first to propose a structural VAR identification strategy to investigate the endogeneity of their uncertainty measures with respect to the business cycle. They find that their measure of macroeconomic uncertainty in recessions is often an endogenous response to output shocks, while their measure of financial market uncertainty is likely to be exogenous. Mumtaz and Theodoridis (2020) investigates empirically and theoretically to what extent monetary policy shocks can affect the expected volatility of macroeconomic variables, particularly of output and inflation. They find an important transmission channel from monetary policy to endogenous uncertainty, both in the data using stochastic volatility in mean VAR and in the model. With respect to their paper, we consider a different shock, an empirical technique that is less computationally demanding and a different medium-scale model that emphasizes the role of the interaction between endogenous uncertainty and firm dynamics.

The paper relates also to works looking at shocks to inflation expectations. As mentioned above, this literature focuses on 'de-anchoring', that is on shocks to long-term inflation expectations. Neri (2021) is particularly close to our research question, because he asks what are the macroeconomics effects of changes in long-term inflation expectations in an empirical VAR on Euro area data identified by a combination of zero, narrative and sign restriction. His main finding is that negative shocks to long-term inflation expectations exerted a downward effect on euro-area inflation in 2013-14 and in 2019. Our paper is similar in spirit, but substantially different as it investigates the macroeconomic effects of short-run - rather than long-run - inflation expectations, it uses a medium-scale DSGE model to quantitatively replicates the effects of the shock, and it stresses the role of endogenous uncertainty in the transmission mechanism of the shock. Clark and Davig (2011) is an early work that look at short-term inflation expectations in a VAR analysis, but it does not focus on the macroeconomic effects.

The rest of the paper is organized as follows. Section 2 describes the theoretical model economy. Section 3 investigates the effects of a shock that increases inflation expectations in the model. Section 4 runs Montecarlo exercise in the spirit of Canova and Paustian (2011) to find the necessary sign restrictions needed to identify an inflation expectation shock and to disentangle it from a standard supply shock. Section 5 uses the sign restrictions of the previous section to estimate a VAR and identify the inflation expectation shock. Section 6 estimates the model using the limited information impulse response matching techniques. Section 7 investigates the asymmetric effects of the shock. Section 8 concludes.

2 Theoretical Model

In this Section, we summarize the theoretical framework of the baseline model considered all along the paper (labeled as *Baseline* henceforth). The Baseline model is a modified version of a standard medium-scale model considered by Fasani et al. (2022). The main ingredients of the medium-scale 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. We assume sticky nominal wages and prices as in 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.

We now present a brief description of the Baseline model, underlying the differences from a standard medium-scale model and the introduction of the inflation expectation shock. The full list of the equations characterising the model is in the Technical Appendix.

The model consists of a closed economy composed of four agents: households, firms, a monetary authority, and fiscal authority.

2.1 Households

Households consume a basket of differentiated retailer-goods, C_t, and their consumption is characterized by external habits. They supply labour, 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 labour bundle of services, L_t.[5] It reads as follows:

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

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 , χ captures the relative weight assigned to labour and $\sigma_L > 0$ represents the inverse of the Frisch elasticity of the labour 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:

$$K_t^s = u_t K_t. \tag{2}$$

The household budget constraint is the following:

$$\begin{aligned} & C_t + B_t + v_t\left(\tilde{z}_t\right)x_t + I_t + FEX_t N_t^E + T_t \leq w_t L_t + \left[r_t^K u_t - a(u_t)\right]K_t \\ & + \frac{1+r_{t-1}}{1+\pi_t}B_{t-1} + + \left[\left(1-\eta_t\right)\left(v_t\left(\tilde{z}_t\right) + j_t\left(\tilde{z}_t\right)\right) + \eta_t l v_t\right]\left(x_{t-1} + N_{t-1}^E\right). \end{aligned} \tag{3}$$

Households enter in the period t earning the real gross income from labour, $w_t L_t$, 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. Defining $\tilde{z}$ as the

[5] Consumer bundle is defined as, $C_t = \left(\int_0^1 c_t^{\frac{\theta_p - 1}{\theta_p}} d\iota\right)^{\frac{\theta_p}{\theta_p - 1}}$, with $\theta_p > 1$, as the elasticity of substitution among the final goods varieties, produced by a continuum of retailers of measure 1.

average level of productivity, in t households earn from firms' value, $v_t(\tilde{z}_t)$, and profits, $j_t(\tilde{z}_t)$, from the fraction $(1-\eta_t)$ of surviving firms, while they earn the liquidation value lv_t for the fraction of exiting firms, η_t. The households spend all the earning to consume and save. T_t is a lump-sum transfer. 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:

$$FEX_t \equiv f^E + ec_t, \tag{4}$$

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:

$$ec_t = \Theta^e \left(\frac{N_t^E}{N_t}\right)^{\varsigma_e}, \tag{5}$$

where $\Theta^e > 0$ and $\varsigma_e > 1$.[6] 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 Bergin and Corsetti (2008), this is a common feature in the firm dynamics literature, and, similarly to familiar quadratic adjustment costs for investments in physical capital, it serves the function of capturing the behavior of entry that responds gradually over time to shocks, as observed in the data.

If a firm exits, the households get its liquidation value:

$$lv_t = (1-\tau) f^E - xc_t. \tag{6}$$

It 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, which, as in Casares et al. (2020), is given by:

$$xc_t = \Theta^x \left(\frac{N_t^X}{N_t}\right)^{\varsigma_x}, \tag{7}$$

where $0 < \tau < 1$, is the share of license fee returning to the households and paid by the fiscal authority once a firm exits the market, $\Theta^x > 0$ and $\varsigma_x > 1$.[7]

[6] Similar assumption on entry congestion extenalities can be found in Bergin and Corsetti (2008).

[7] 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.

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

$$N_t = (1 - \eta_t) \left(N_{t-1} + N_{t-1}^E \right). \tag{8}$$

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, as:

$$a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2, \tag{9}$$

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

Physical capital accumulates as follows:

$$K_{t+1} = \left(1 - \delta^K - S\left(\frac{I_t}{K_t} \right) \right) K_t + I_t, \tag{10}$$

where δ^K is the depreciation rate, and $S\left(\frac{I_t}{K_t}\right)$ are capital adjustment costs defined as in Hayashi (1985), as:

$$S\left(\frac{I_t}{K_t} \right) = \frac{\phi_K}{2} \left(\frac{I_t}{K_t} - \delta^K \right)^2. \tag{11}$$

The implied first-order conditions of the household problem are listed in the Technical Appendix. They are the households' labour 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 labour to an intermediate labour union which differentiates the labour 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.

2.2 Firms

As in Rossi (2019) and in Fasani et al. (2022), 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 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.

2.2.1 Intermediate Sector

Each firm in the intermediate sector produces a differentiated good under monopolistic competition and flexible prices.[8] 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:

$$y_{\iota,t} = A_t z_{\iota,t} l_{\iota,t}^{1-\alpha} \left(k_{\iota,t}^s\right)^\alpha , \tag{12}$$

where $l_{\iota,t}$ and $k_{\iota,t}^s$ are respectively, the amount of labour 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. The variable A_t is the aggregate TFP. Its logarithm, labelled as $\varepsilon_{A,t} = ln(A_t)$, follows an exogenous AR(1) process with zero mean and a standard deviation equal to σ_A, that is:

$$\varepsilon_{A,t+1} = \rho_A \varepsilon_{A,t} + \sigma_A u_{\varepsilon_A,t+1}. \tag{13}$$

This sector is characterised by endogenous firm dynamics. The timing characterising 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, $v_t\left(\widetilde{z}\right) = FEX_t$. Note that the value of the firm facing the average productivity corresponds to the stock price of the

[8] 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.

economy. The latter is so given by:

$$v_t\left(\widetilde{z}_t\right)=\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\left(1-\eta_{t+1}\right)\left(v_{t+1}\left(\widetilde{z}_{t+1}\right)+j_{t+1}\left(\widetilde{z}_{t+1}\right)\right)+\eta_{t+1}lv_{t+1}\right)\right], \tag{14}$$

where λ_t is the marginal utility of consumption at time t, and $j_t\left(\widetilde{z}_t\right)$ 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.[9] 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' productivity depend on the cut-off level of productivity in the economy, $\overline{z}_t$, which is endogenously determined through the following exit condition:

$$v_t\left(\bar{z}_t\right)=lv_t, \tag{15}$$

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

$$v_t\left(\bar{z}_t\right)=j_t\left(\bar{z}_t\right)+\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(1-\eta_{t+1}\right)v_{t+1}\left(\bar{z}_{t+1}\right)\right]. \tag{16}$$

Equation (16) states that the value of the marginal firm is given by its current profit $j_t\left(\bar{z}_t\right)=y_t\left(\bar{z}_t\right)-w_tl_{\bar{z},t}-r_t^Kk^s_{\bar{z},t}$, with $w_tl_{\bar{z},t}$ the cost of labour and $r_t^Kk^s_{\bar{z},t}$ the cost of capital services of the marginal firm plus the continuation value.

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 $z_{\min}$. This ensures the existence of an endogenously determined number of exiting firms in each period. The number of firms with productivity levels between $z_{\min}$ and the cutoff level

[9]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 $z_{\min}$.

$\bar{z}_t$ exit the market without producing.

2.2.2 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 the intermediate goods 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, which for simplicity and without loss of generality equals the elasticity of demand of the final goods varieties. Retailer's minimum expenditure problem implies the following demand function for the intermediate good ι:

$$y_{\iota,t} = \left(\frac{p_{\iota,t}}{P_t^I}\right)^{\theta_p} Y_t^I(k), \tag{17}$$

implying and 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:

$$1 = \frac{\theta_p}{\theta_p - 1}\rho_t^I - \frac{\phi_p}{\theta_p - 1}(\pi_t - 1)\pi_t + \frac{\phi_p}{2}(\pi_t - 1)^2 + \frac{\phi_p}{\theta_p - 1}E_t\left\{\Lambda_{t,t+1}(\pi_{t+1} - 1)\pi_{t+1}\frac{Y_{t+1}}{Y_t}\right\}, \tag{18}$$

where ϕ_p is the adjustment price parameter, and ρ_t^I the relative price $\frac{P_t^I(k)}{P_t}$. By symmetry, 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.

2.3 Monetary and Fiscal Authority

The central bank sets the nominal interest rate following a standard Taylor-type rule:

$$\log\left(\frac{1+i_t}{1+i}\right) = \phi_R \log\left(\frac{1+i_{t-1}}{1+i}\right) + (1-\phi_R)\left(\phi_\pi \log\left(\frac{\pi_t}{\pi}\right) + \phi_y \log\left(\frac{y_t}{y}\right) + \phi_{dy}\log\left(\frac{y_t}{y_{t-1}}\right)\right), \tag{19}$$

where ϕ_π, ϕ_y and ϕ_{dy} are the elasticities of the nominal interest rate with respect to the deviation of the inflation from their long-run target, to the deviation of output from its steady state value and to the growth rate of output. The parameter ϕ_R is the interest rate smoothing parameter.

The fiscal authority runs the following balanced budget:

$$T_t = f^E N_t^E - (1-\tau)\, f^E N_t^X, \tag{20}$$

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.

2.4 Inflation Expectation Shocks and Endogenous Uncertainty

The main shock studied in the model economy is a shock to inflation expectations. We slightly depart from the standard rational expectations assumption by assuming that agents' forecast follows the rational expectation hypothesis, but this forecast is hit by shock, as:

$$E_t \pi_{t+1} = [\pi_{t+1}^e] e^{\varepsilon_{\pi,t+1}}, \tag{21}$$

with π_{t+1}^e being the rational expectation in t of *t+1* gross inflation and $\varepsilon_{\pi,t+1}$ being an exogenous process that allows inflation expectations to deviate from their rational expectation solution. This process has zero mean and a constant standard deviation equal to σ_π:

$$\varepsilon_{\pi,t+1} = \rho_\pi \varepsilon_{\pi,t} + \sigma_\pi u_{\varepsilon,t+1}. \tag{22}$$

Endogenous Uncertainty. A novel part of our analysis is that we focus on how shocks to inflation expectations affect uncertainty in the model. To this scope, as in Mumtaz and Theodoridis (2020), we use alternatively the term volatility of expected variables or measured uncertainty to refer to the heteroschedastic response of a variable, say x_t, defined as:

$$\tilde{\sigma}_{x,t} = 100 ln(\frac{\sigma_{x,t}}{\sigma_x}), \qquad \text{where} \qquad \sigma_{x,t}^2 = var_t(x_t) = E_t[x_{t+1} - E_t x_{t+1}]^2, \tag{23}$$

and σ_x is the stochastic steady-state standard deviation of the variable x_t. This is as in Basu and Bundick (2017) and also consistent with the definition of expected volatility studied by Jurado et al.

(2015). Using this definition, we construct a measure for output uncertainty, which is defined as the volatility of the expected real GDP, a measure of inflation uncertainty, defined as the volatility of expected inflation and finally a measure of equity return uncertainty, defined as the volatility of the expected return on equity.

2.5 Aggregation and Market Clearings

The economy aggregate output is:

$$Y_t = A_t N_t^{\frac{1}{\theta_p - 1}} \widetilde{z}_t \left(L_t\right)^{1-\alpha} \left(K_t^s\right)^{\alpha}, \tag{24}$$

while the resource constraint of the economy is:

$$Y_t = C_t + I_t + a\left(u\right) K_t + N_t^E ec_t + N_t^X xc_t + PAC_t + WAC_t, \tag{25}$$

where $PAC_t = \frac{\phi_p}{2}\left(\pi_t - 1\right)^2 Y_t$ and $WAC_t = \frac{\phi_w}{2}\left(\frac{w_t}{w_{t-1}}\pi_t - 1\right)^2 Y_t$ are respectively the price and wage adjustment costs.

3 Model Dynamics

This Section shows the model dynamics in response to an unexpected increase in inflation expectations. First, we illustrate the calibration strategy. Second, we compute the impulse response function (IRFs) of the main macroeconomic variables of our Baseline model to a positive inflation expectation shock, that is to a shock that increases inflation expectations. For better understanding the role played by uncertainty in affecting the dynamics of the main macro variables we compare the IRFs obtained with the Baseline model, that is with the model approximated up to a third order, with the IRFs obtained solving the same model up to a first order approximation, that is in a model where the uncertainty contribution is absent.

3.1 Calibration

The auto-regressive coefficients of the inflation expectation shock, $\varepsilon_{\pi,t+1}$, is equal to 0.9 and its innovation $u_{\varepsilon,t} \sim N\left(0, 0.01^2\right)$. The parameters of the technology shock follow the same calibration of the inflation expectation shock. We back out the model-implied VXO similarly to Basu and Bundick

(2017).[10]

The next set of parameters we calibrate concerns household preferences. The discount factor, β, is set at 0.99, corresponding to an annualized real interest rate of about 4%. The coefficient of the relative risk aversion, σ_C, is set to 1.5, the elasticity of labour supply, σ_L, to 5, the habits persistence parameter to 0.6. All values of the parameters in the utility function lay within admissible intervals of estimates in the literature (e.g., Smets and Wouters, 2007; Christiano et al., 2005). 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% per year. 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), while the capital adjustment costs parameter, ϕ_K, is set to 5. 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 9% for the period considered in the VAR 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%. This value is in line with the literature on firm dynamics (e.g., Ghironi and Melitz, 2005; Bilbiie et al., 2012). We set the markup in the labour market as the benchmark for the good market, so that the elasticity of substitution among labour 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 elasticity's of entry and exit congestion externality, ς_e and ς_x, is set to 2 and 1 respectively. 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 **?**. 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. The share of the fixed entry cost of the exiting firms rebated to the households is fixed to 25% so that the parameter τ is set to 0.75.

Parameters describing the price and wage setting are calibrated as follows. We set the Rotemberg

[10]We construct a model counterpart to the VXO index to then link the dynamics of the DSGE with the one in the VAR. We define the equity return and the expected conditional volatility of the equity return, i.e. the model-implied VXO index, as in Basu and Bundick (2017), (see equations 9 and 10 in the paper). Also, we test our results by using a different definition of the equity return that is closer to our set-up of endogenous firm entry and exit. The alternative defines the return of firm equity as $R^E_{t+1} = \frac{(1-\eta_{t+1})(v_{t+1}(\tilde{z}_{t+1})+j_{t+1}(\tilde{z}_{t+1}))+\eta_{t+1} l v_{t+1}}{v_t}$, namely it allows for the probability of exiting and the liquidation value to affect the equity return. Our simulations, however, indicate that the two measures of equity return produce almost identical responses for the expected conditional volatility.

parameter of price adjustment cost ϕ_p and of the of nominal wage adjustment cost ϕ_w both equal to 40, though in the Montecarlo exercise presented in Section 4 we test the robustness of the results by considering higher and lower values for both parameters.

Finally, we set the coefficients in the Taylor rule as $\phi_R = 0.75$, $\phi_\pi = 2.5$, $\phi_y = 0.01$ and $\phi_{dy} = 0.05$.[11]

3.2 IRFs to Inflation Expectation Shocks

This Section comments on the transmission of the shock to inflation expectations in the DSGE model. To examine the dynamic effects of this shock, we solve the model using third-order approximations of the equilibrium conditions around the steady-state. We follow the procedure suggested by Fernández-Villaverde et al. (2015) to compute the IRFs in deviation from the stochastic steady state.

We carry out the IRFs analysis as follows. First, we show the IRFs of the third-order solution of the baseline model and we compare them with the same IRFs obtained using the first-order approximation of the same model, where the uncertainty contribution is absent. This comparison allows us to measure the uncertainty contribution. Second, we test the robustness of the third-order solution of the model by running a Montecarlo exercise under different parameterization of some key parameters and under alternative Taylor rules.

Figure 2 shows the IRFs to a 1% exogenous increase in inflation expectations. Blue solid lines show the responses of the main variables obtained using the third-order approximation of the model, while red dashed lines show the responses of the same variables obtained using the first-order approximation of the model. In both specifications, a shock that increases inflation expectations is recessionary and inflationary. In particular, though the size of the shock is not particularly high, it represents quite a big impact for the economy. Indeed, it implies an increase in inflation of about 1.5 percentage point followed by substantial drop in output of about 3 percentage points in the model approximated up to a first order and even larger drop in the third order model. The increase in the expected price level causes an increase in the price level that triggers, through the Taylor rule, an increase in the nominal and real interest rate. This generates a recessionary effect that decreases output, consumption, and investment in physical capital. At the same time, the shock is followed by a drop in hours worked and wages. The presence of firm dynamics amplifies the effect of the shocks via the extensive margin mechanism. The recessionary shock is followed by a reduction in the firm value, i.e., the stock price, which brings about a decrease in investments in new firms and thus in firm entry. In contrast, firm

[11] The calibration guarantees the uniqueness of the equilibrium and it is in the range of the values estimated for the U.S. economy (e.g., Smets and Wouters, 2007). We check, however, that the findings are not qualitatively altered by the choice of the coefficients in Taylor rule for neither the Baseline model nor the other specifications.

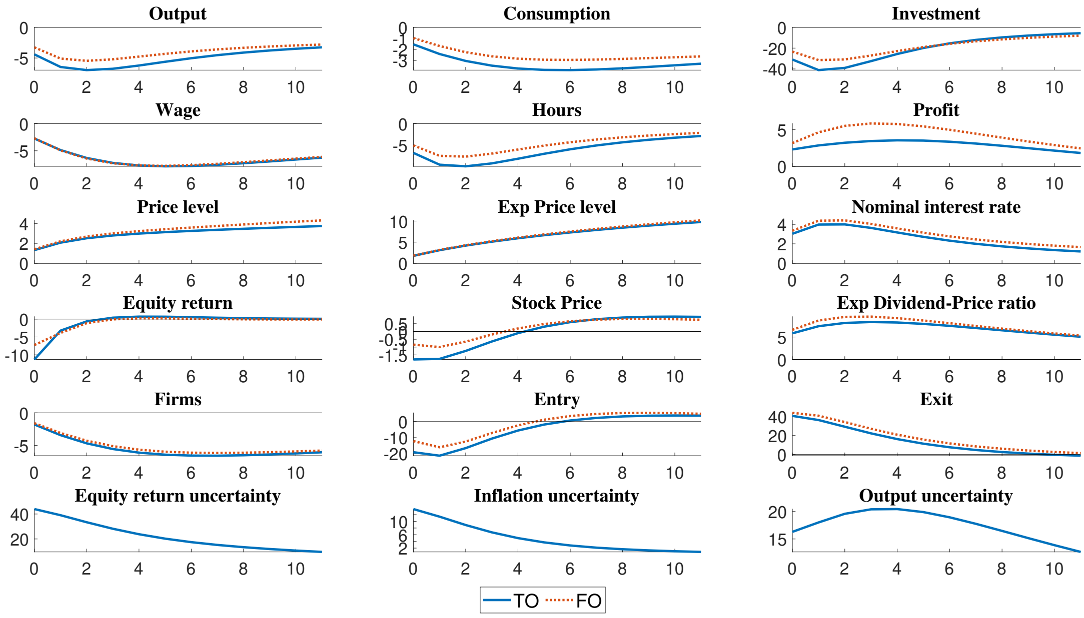

Figure 2: **Model Dynamics:** responses to inflation expectation shock. First order vs third order approximation.

exit increases and stock of firms in the market declines. Notice that the dividend-to price ratio, that is the ratio between the expected profits and stock price increases. This is due to the large drop in the stock price and a rather small rise in profits, because firm costs for labor and capital fall more than total revenues.

These patterns are common to the third-order solution of the model and to the first-order solution of the model. However, the recessionary effect of the shock is stronger when the model is approximated up to the third order, thus implying that endogenous uncertainty contributes to making the recession deeper. At the same time, the stronger drop in output moderates the rise in the price level which is indeed lower than in the first-order approximation. In order to better understand the role of uncertainty in the model Figure 3 shows what is the uncertainty contribution to each variable. As in Mumtaz and Theodoridis (2020), we define the uncertainty contribution as the difference between the IRFs obtained using the third-order solution of the model and those obtained using the first-order solution. After a few periods from the impact of the shock, the drop in output is about 1.5% greater under the third-order solution than under the first-order solution of the model. When compared with the responses in Figure 2, this suggests that uncertainty contribution to the drop in output is about a half. Similarly, uncertainty seems to account for almost $1/4^{th}$ of the fall in consumption, for around $1/4^{th}$ of declining investments, and $1/3^{rd}$ of hours worked. It also explains almost $1/3^{rd}$ of the drop in firm entry. Overall, our findings suggest that the endogenous uncertainty channel plays a sizeable

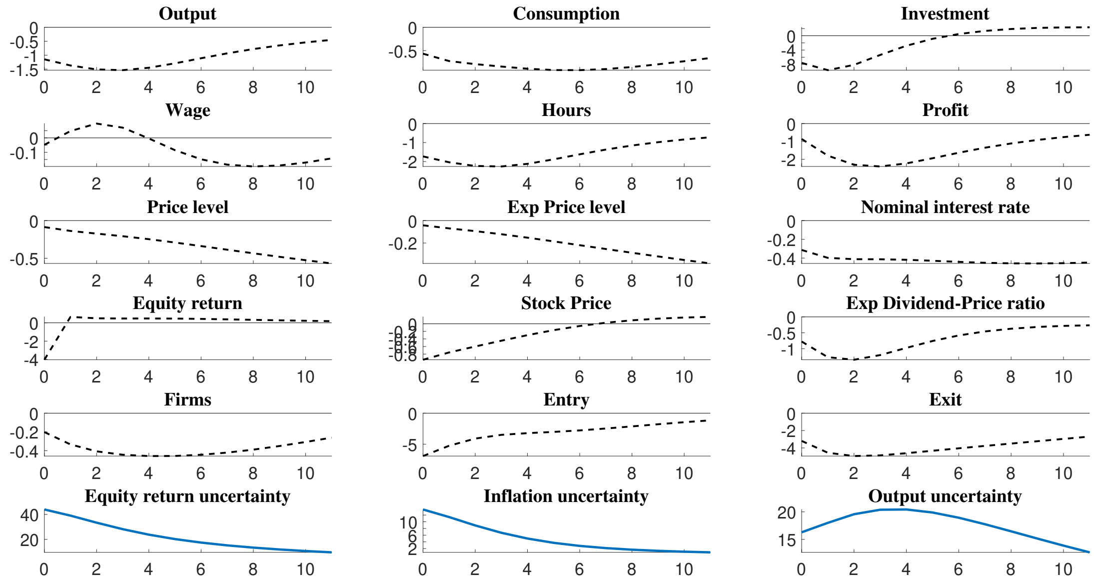

Figure 3: **Uncertainty Contributions:** difference between the response derived by using the third order solution of the model minus the responses produced using only the first order solution.

role in the transmission of the inflation expectations shock. The last row of Figures 2 and 3 show the dynamics of three measures of endogenous uncertainty: the expected volatility of output, inflation, and equity return, as defined in equation (23). An increase in inflation expectations is followed by a substantial increase in the expected volatility of inflation, output, and equity returns. As it will be clear in the next Section, these patterns for the expected volatility are robust to alternative calibrations.

4 Montecarlo simulations

The objective of this Section is to establish a set of theory robust sign restrictions that we can use to separately disentangle shocks to inflation expectations from standard supply shocks. The latter is a negative TFP shock, see (13), that as the inflation expectation shock is stagflationary, that is, it reduces output, increases inflation, as well as its expectations. We follow Canova and Paustian (2011) and run the following exercise. For a set of key structural parameters of the model we make one independent draw from a uniform distribution specific to each parameter and we compute the implied IRFs to the two shocks using this set of parameters. Then, we repeat this step 10,000 times. The final result is a distribution of impulse responses that can be used to establish combinations of sign restrictions unique to each shock under consideration. Table 1 reports chosen bounds for the uniform distributions of parameters considered in this exercise. All the other parameters are calibrated as in

Table 1: Parameter Bounds for the Monte Carlo exercises: uniform distributions.

	Benchmark model	*LB*	*UB*
"Deep" parameters			
γ_p	Rotemberg Adjustment Cost - Price	30	100
γ_w	Rotemberg Adjustment Cost - Wage	30	100
γ_i	Investments Adjustment Cost	2	7
Shocks' persistence			
ρ_a	Persistence Supply shock	0.35	0.9
ρ_π	Persistence Inflation Expectations shock	0.35	0.9
Shocks' standard deviations			
σ_a	Std. Supply shock	0.0005	0.0015
σ_π	Std. Inflation Expectations shock	0.0005	0.0015
Taylor rule			
ϕ_π	Coefficient Inflation	2	5
ϕ_y	Coefficient Output	0.005	0.015
ϕ_{dy}	Coefficient Output growth	0.01	0.1
ϕ_R	Interest rate smoothing	0.5	0.9

Notation: LB $\rightarrow$ lower bound; UB $\rightarrow$ upper bound.

the previous Section.

Figure 4 and 5 show the distribution of the IRFs in response to an inflation expectation shock and to a supply shock respectively, resulting from the simulation exercise. They report the Median (solid line), 90%, and 68% credible bands based on the 10,000 draws. The two shocks show very similar patterns, with the inflation expectations shocks having stronger impact on all the variables. Both shocks are recessionary and imply an increase in the price level, in the price level expectations and in the interest rate. The patterns of all the variables are qualitatively similar under the two shocks, except for the response of profits, the expected dividend-price ratio and output uncertainty. Notice that, while these three variables increase in response to a shock that increases inflation expectations, they decrease in response to a negative supply shock. Hence, the sign of these variables is crucial in our identification strategy, since they allow to disentangle an inflation expectation shock from a more standard supply shock. In this respect, we are the first to use a model based identification strategy for estimating inflation expectations and supply shocks that relies on the sign of the response of the expected dividend-price ratio and output uncertainty.

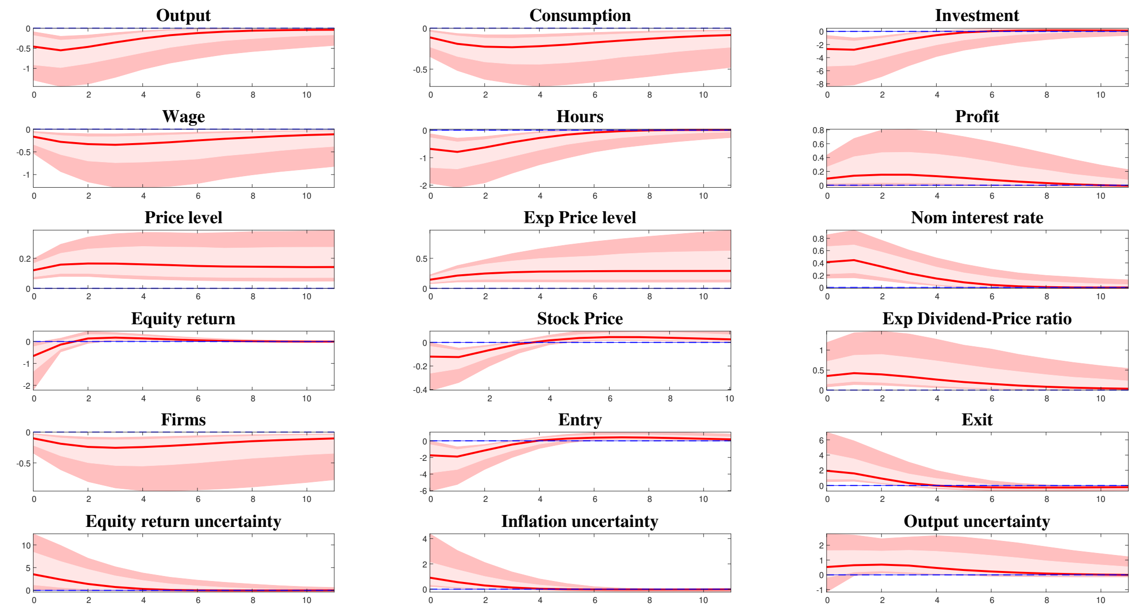

Figure 4: Dynamic responses to an inflation expectations shock. Montecarlo simulation of the model as in Canova and Paustian (2011).

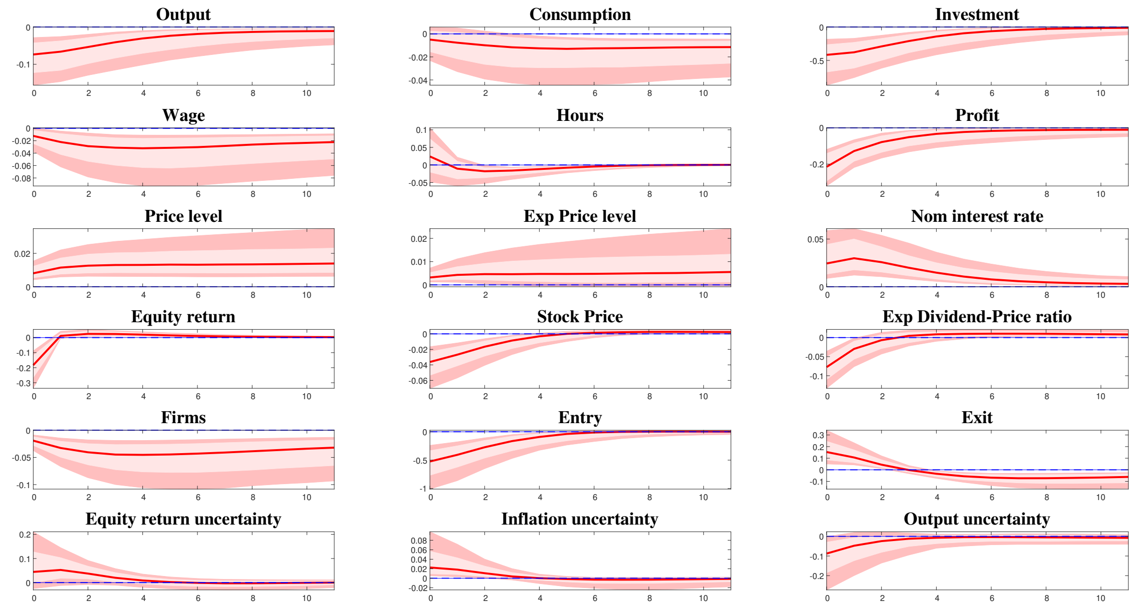

Figure 5: Dynamic responses to a supply shock. Montecarlo simulation of the model as in Canova and Paustian (2011).

	Expectations Shock	Supply shock
log(real GDP)	−	−
log(SPF GDPD 1-q ahead forecast)	+	/
log(GDPD)	/	+
Equity returns	−	−
Dividend to price ratio	+	−
VXO	+	+
SPF Dispersion of RGDP forecast	+	−
SPF Dispersion of GDPD forecast	+	+

Table 2: Sign Restrictions. SPF → Survey from Professional Forecasters, GDPD → GDP Deflator, RGDP → real GDP

5 VAR

To investigate the impact of a shock to inflation expectations, we estimate a VAR with 8 variables using a combination of sign restrictions derived in the previous section and a of narrative sign restriction in the spirit of Antolín-Díaz and Rubio-Ramírez (2018). The series considered in the VAR are: real GDP, 1-q ahead forecast of GDP deflator, GDP deflator, equity return, dividend-to-price ratio, VXO, 1-q ahead forecast dispersion of real GDP, 1-q ahead forecast dispersion of the GDP deflator. The data are collected at the quarterly frequency from 1971:q1 to 2019:q2. The series of real GDP (GDPC1), GDP deflator (GDPCTPI), and VXO (VXOCLSx) are retrieved from the Federal Reserve quarterly database for macroeconomic research (FRED-QD database). The measure of equity return is the value-weighted total stock market return (vwretd) taken from CRSP. Data on the divident-to-price ratio are obtained following Shiller (2015) and sourced from his webpage. We use data from the Survey of Professional Forecasters by the Philadelphia FED for inflation expectations and uncertainty on GDP and inflation. We take the 1-quarter ahead mean forecast on GDP deflator and calculate standard deviation on 1-quarter ahead individual forecasts on real GDP (RGDP) and GDP deflator (PGDP), respectively. Logarithm transformation applies for real GDP, GDP deflator, and expected GDP deflator. We use Jeffrey (uninformative) prior for the baseline SVAR specification but we test the empirical findings under different priors. The sign restrictions we imposed are derived from Figures 4 and 5 and summarised in Table 2. As suggested by the Montecarlo exercise in the previous Section, the signs attached to the responses of the dividend-price ratio and output uncertainty are key to disentangle an inflation expectations shock from a supply shock. Further, notice that we do not impose any sign on the response of the price level to an inflation expectation shock.

Furthermore, following Antolín-Díaz and Rubio-Ramírez (2018) we impose a narrative sign restric-

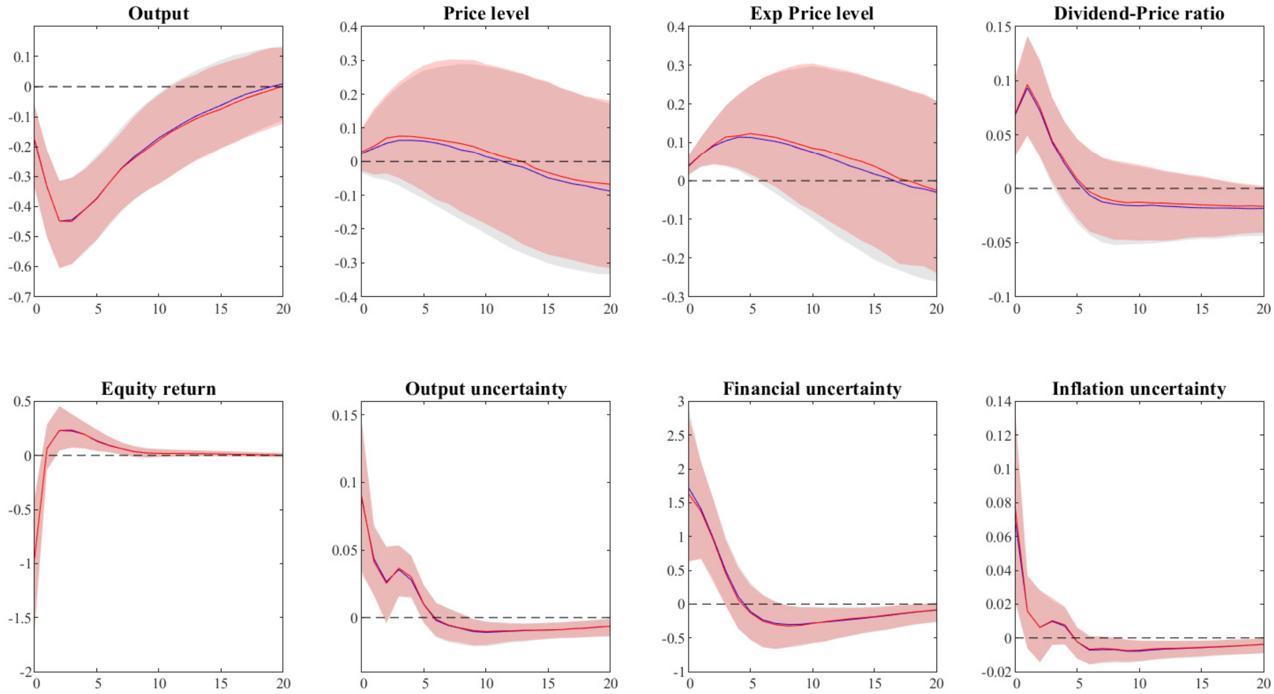

Figure 6: VAR impulse response functions to an **inflation expectation shock** (68% percentile): in grey the estimated IRFs obtained using only sign restrictions, in red the estimated IRFs obtained using sign restrictions and the narrative.

tion to better identify the inflation expectations shock. Paul Volcker was nominated to fight inflation and this was publicly known during the nomination process.[12] We use this information as a narrative restriction to identify the impact of inflation expectation shocks. In particular, we assume that the nomination of Volcker caused a negative shock on inflation expectations. Thus, we impose the narrative restriction that in Q3/1979 the shock to inflation expectations is negative.

Figure 6 shows the IRFs to an inflation expectation shock with and without the narrative sign restriction. Overall, the narrative sign restriction does not matter in terms of median impulse response functions and helps very little for the significance of the responses.

The Technical Appendix reports the IRFs to a supply shock, the relative contribution of the two shocks in explaining the volatility of the variables at different horizons and the series of identified

[12] During the hearing before the Committee on Banking, Housing and Urban Affairs of the United States Senate on July 30, 1979, the soon-to-be Fed Chairman made his intentions regarding the fight against high inflation clear. To a question from the chairman of the committee, Volcker stressed the importance of stability for economic growth, explicitly mentioning the accelerating inflation: *"I have spoken out and I expect to continue to speak out on the need for stability, broadly conceived — thinking of it in terms of our domestic inflation, thinking of it in terms of the value of the dollar internationally. I speak out of a very strong conviction that this sense of stability is necessary in order to assure the prosperity and growth of our economy at home and to deal with those problems of unemployment, poverty and all the others. I don't think we can build on a sense of instability—accelerating inflation, instability of the dollar abroad—if we want to deal constructively with those problems of the domestic economy."* Paul A. Volcker, from the Nomination Hearing before the Committee on Banking, Housing, and Urban Affairs, United States Senate, Ninety-Sixth Congress, First Session on July 30, 1979.

structural shocks. The Technical Appendix also reports several robustness checks. First, it shows that our results are robust to alternative VAR estimation which uses the same sample considered in the main text, but alternative priors and trends specifications. Second, it reports the IRFs obtained using two alternative samples: (i) a sample starting in 1985:q1 and ending in 2019:q2, that excludes the effects of the oil shock and hyperinflation period; (ii) a sample starting in 1971:q1 and ending in 2007:q4, that excludes the last great recession. Finally, the Technical Appendix checks the possible tension between our non-linear DSGE model and the linear VAR in our empirical exercise. Specifically, we estimate the VAR using artificially generated data from simulating our non-linear DSGE model. The Technical Appendix shows that VAR-IRFs obtained with simulated data closely follow the DSGE-IRFs. This corroborate our choice for the empirical methodology. The VAR is successful at recovering the true impulse responses from the model.

6 Model Estimation

In this Section, we estimate a set of the model parameters that characterise our Baseline model conditional on an inflation expectations shock. Importantly, to understand better the role played by endogenous uncertainty we compare the model dynamics obtained using the parameters estimated using the third order solution of the Baseline with that obtained using the first order approximation of the same model. A set of parameters is fixed a priori as in Section 3.1 for both the third and first order approximation of the Baseline model. The remaining parameters are 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 (2020). More precisely, these parameters are estimated using the SVAR-IRFs of real GDP, consumer price index, expected price index and the return on equity to the identified inflation expectation shock. With the estimated parameters in hand, obtained using alternatively the third-order and first-order solution of the model, we simulate the dynamic IRFs of the variables to an unexpected increase in inflation expectations.

Table 3 shows the list of the estimated parameters and their values obtained under the two estimation exercises, e.g. using the SVAR-IRFs and the model-IRFs for both the first order and the third order solution of the same model (labelled as FO and TO, respectively, in the Table). The resulting parameters are reported in the third and in the fourth column of Table 3, respectively. First, the last row of the Table reports the value of the weighted matrix used to minimize the IRFs matching. It shows that the minimum reached using the third order approximation is smaller than the minimum

Estimated Parameters			
		TO	*FO*
"Deep" parameters			
γ_p	Rotemberg Adjust. Cost - Price	18.9	19.1
γ_w	Rotemberg Adjust. Cost - Wage	112.8	42.6
γ_i	Investments Adjustment Cost	5.78	7.28
Shock persistence and Std.			
σ_π	Std. of Inflation Expect. shock	0.0003	0.0006
ρ_π	Persist. Inflation Expect. shock	0.7680	0.5448
Taylor rule			
ϕ_π	Coefficient Inflation	3.96	4.55
ϕ_y	Coefficient Output	0.0450	0.0189
ϕ_{dy}	Coefficient Output growth	0	0.0025
ϕ_R	Interest rate smoothing	0.3890	0.7776
Value Function		44.94	61.45

Table 3: Parameter Estimates through IRFs matching. FO $\rightarrow$ First Order solution; TO $\rightarrow$ Third Order solution

reached using the first order approximation of the same model. This suggests that the third order approximation of the model better minimizes the distance between the VAR-IRFs and the model-IRFs than the first order approximation. This is clear from looking at Figure 7 which reports in the same panels the model-IRFs and the VAR-IRFs and shows that the third order approximation of the model generates IRFs that are closer to those obtained in the VAR. Second, the third-order approximation of the Baseline model requires a substantially larger degree of wage rigidity, while the degree of price rigidity and of the investments adjustment cost are almost equal across the two models. The estimated standard deviation of the inflation expectations shock, σ_π, is higher in the first order approximation of the model, while the third order approximation of the model requires a higher persistence of the shock, ρ_π. The Taylor rule response to inflation is similar between the two models, that instead slightly differ regarding the response to output, output growth - which is zero for the third-order model - and, more substantially, for the persistence parameter of the rule, which is less persistent for the third-order model. Finally, Figure 8 compares the IRFs of all the variables (included those that are not matched in the VAR) obtained using the estimated parameters of the first and of the third order solution of the model. This comparison confirms the larger drop in output, consumption, investments and firm entry implied by the third order solution of the model. Thanks to the presence of a stronger degree of wage rigidity the drop in the real wage is substantially lower, but more persistent in the model approximated up to the third-order.

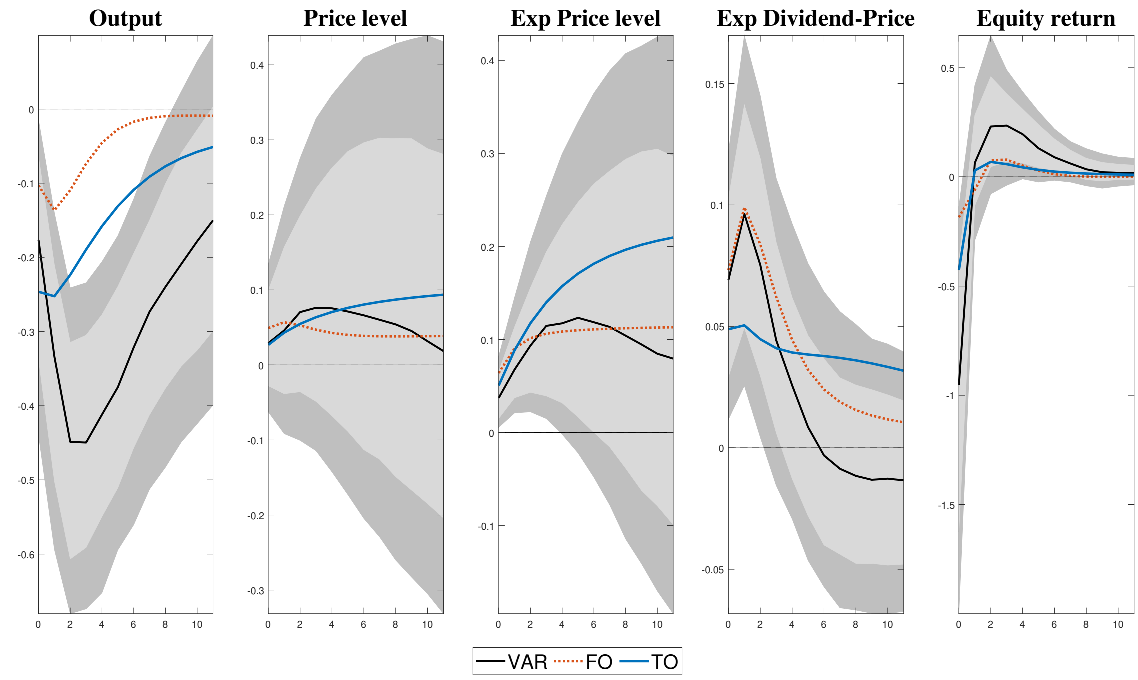

Figure 7: IRFs to inflation expectations: VAR-IRFs vs. IRFs implied by the estimated models, FO vs TO model.

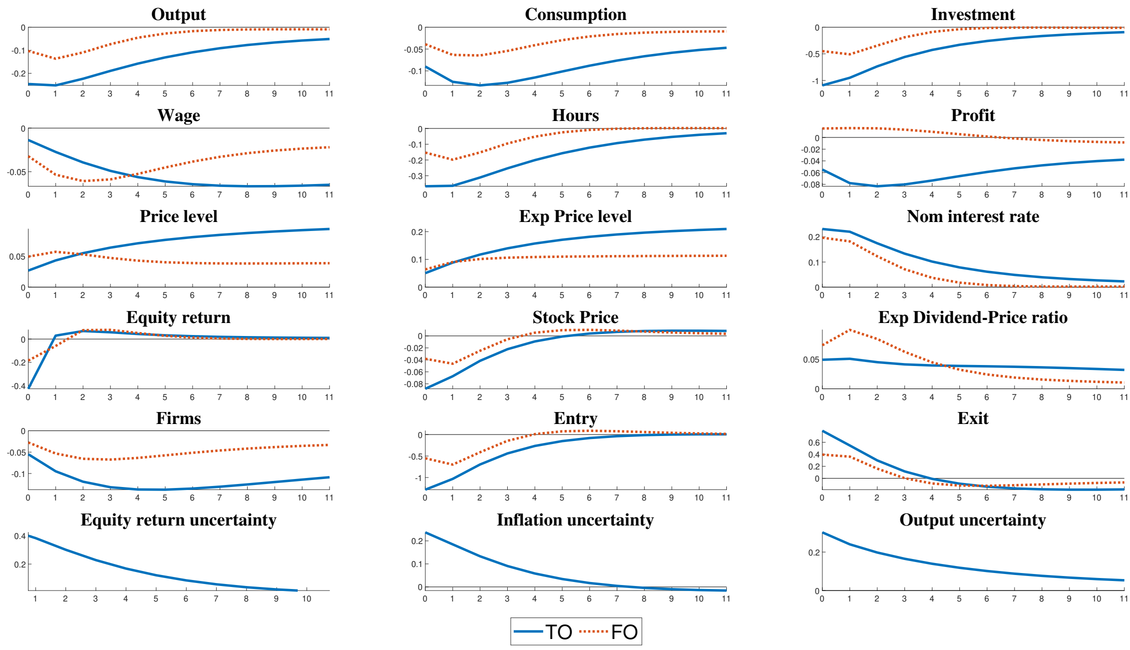

Figure 8: Dynamic responses to inflation shock using estimated parameters: FO vs TO model.

6.1 Contribution of firm dynamics

This section analyses the contribution of firm dynamics by comparing the estimation done using the Baseline model with the estimation obtained by the same model without firm dynamics, where the number of firms is constant. We solve this model using the third order approximation and we label it as *TO-no-firms* model. The model without firms dynamics exhibits, with respect to our baseline model: (i) a higher degree of price stickiness and a lower degree of wage stickiness; (ii) a worse fit of the data in terms of value function; (iii) muted effects of the shock on real variables, as shown in Figure 9. Firm dynamics therefore is an important mechanism to amplify and propagate the shock, and this mechanism is indeed supported by the data. Notably, the model with firm dynamics requires higher wage rigidity, but lower price rigidity. This result seems of particular interest and it is consistent with the recent findings by Bilbiie and Melitz (2020). These authors show in a model that endogenous entry-exit radically changes the consequences of nominal rigidity 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 level shock that increases inflation expectations and that the endogenous stickiness implied by frictional entry-exit requires a lower degree of price rigidity.

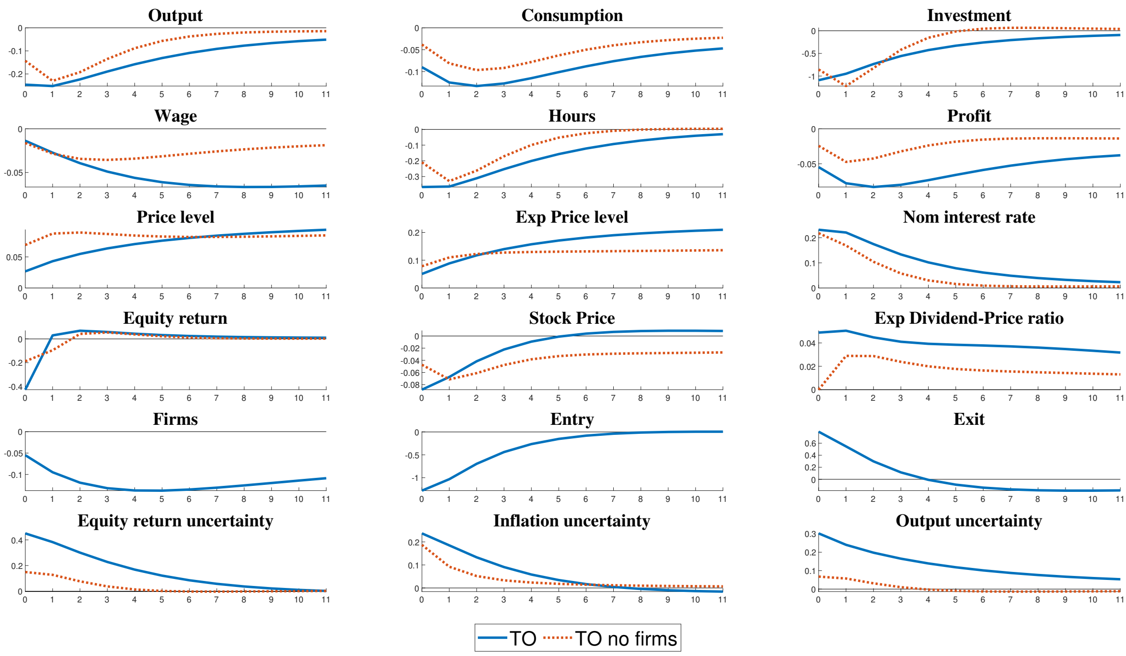

Figure 9: IRFs to inflation expectations shock using estimated parameters TO vs TO no firms model

Estimated Parameters		*TO*	*TO-no-firms*
"Deep" parameters			
γ_p	Rotemberg Adjust. Cost - Price	18.9	32.32
γ_w	Rotemberg Adjust. Cost - Wage	112.8	95.42
γ_i	Investments Adjustment Cost	5.78	2.11
Shock persistence and Std.			
σ_π	Std. of Inflation Expect. shock	0.0003	0.0006
ρ_π	Persist. Inflation Expect. shock	0.7680	0.4988
Taylor rule			
ϕ_π	Coefficient Inflation	3.96	1.98
ϕ_y	Coefficient Output	0.0450	0.0055
ϕ_{dy}	Coefficient Output growth	0	0.0943
ϕ_R	Interest rate smoothing	0.3890	0.5551
Value Function		44.94	62.24

Table 4: Parameter Estimates through IRFs matching. TO no firms $\rightarrow$ Third Order solution of model with no firm dynamics; TO $\rightarrow$ Third Order solution of baseline model

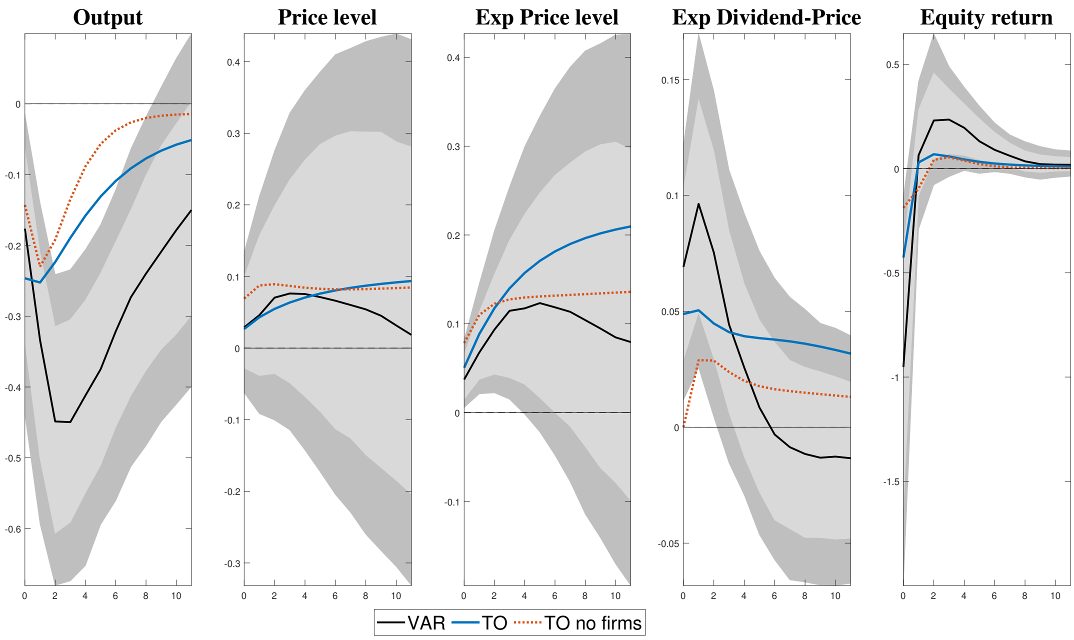

Figure 10: IRFs to inflation expectations shock of the matched series and those implied by the estimated models, TO vs TO no firms model.

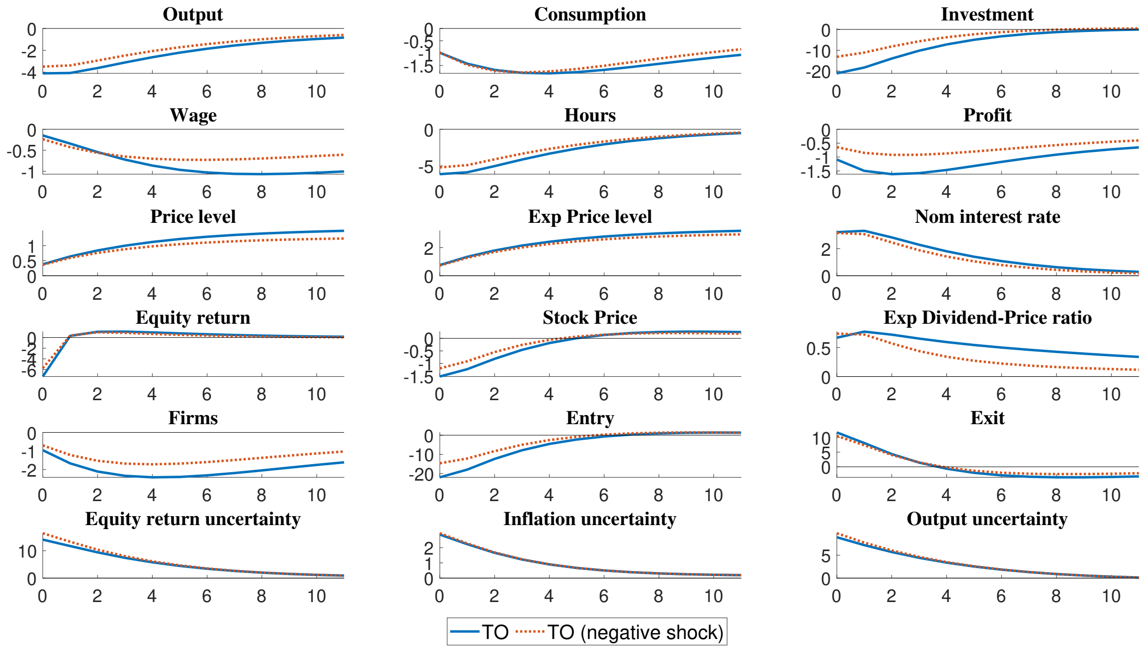

Figure 11: Simulating large shocks using TO calibration: positive (inflationary) versus negative (deflationary) shock (negative IRFs multiplied by -1.)

7 Asymmetries

This Section investigates the possible asymmetric effect of shocks that affect inflation expectations both theoretically and empirically. More precisely, we ask if the effects of shocks that increase inflation expectations are symmetric to the ones of shocks that reduce inflation expectations.

7.1 Model Asymmetries

In order to investigate this question in the theoretical model we proceed as follows. We hit the third order solution of the Baseline theoretical model by a shock that increase inflation expectations - labelled as positive shock - and by a shock that decreases inflation expectations - labelled as negative shock- , using the estimated parameters. Figure 11 shows the IRFs to an exogenous increase in inflation expectations (red solid lines) that increases current inflation by half percentage point and to an exogenous decrease in inflation expectations (black dashed lines) that reduces current inflation by half percentage point. Notice that in the latter case, the IRFs vectors have been multiplied by -1, so that the sign of these IRFs is the same of the ones obtained in response to a positive inflation expectations shock. The first panel in Figure 11 shows that the a positive shock to inflation expectations, that is a shock that increases inflation expectations, has a stronger effect on output than a shock that reduces inflation expectations. Similarly a positive shock to inflation expectations has a stronger effect on

Estimated Parameters			
		Shock(+)	*Shock*(−)
"Deep" parameters			
γ_p	Rotemberg Adjust. Cost - Price	18.9	34.70
γ_w	Rotemberg Adjust. Cost - Wage	112.8	92.59
γ_i	Investments Adjustment Cost	5.78	6.11
Shock persistence and Std.			
σ_π	Std. of Inflation Expect. shock	0.0011	0.0006
ρ_π	Persist. Inflation Expect. shock	0.7680	0
Taylor rule			
ϕ_π	Coefficient Inflation	3.96	2.83
ϕ_y	Coefficient Output	0.0450	0.0233
ϕ_{dy}	Coefficient Output growth	0	0
ϕ_R	Interest rate smoothing	0.3890	0.7100
Value Function		44.94	70.61

Table 5: Parameter Estimates through IRFs matching. Notation: Shock (-) → Negative shock; Shock (+) → Positive shock.

consumption and investments. The positive shock implies also a stronger response in the price level and in its expectations. Hours worked, real wages and entry of new firms exhibit similar patterns. Overall, a shock that increases inflation expectation have stronger effects than a shock that decreases the expectations. This result is obtained calibrating the model with the same parameters both under a positive shock and under a negative shock. In order to capture the importance of the asymmetries, in the next section we estimate the model parameters repeating the matching exercise presented in the previous Section, however using alternatively the model-IRFs to a positive and to a negative inflation expectations shock.

7.2 Symmetric VAR and Asymmetric Model

This section repeats the estimation done in Section 6 using the model-IRFs of the third order solution of the model obtained hitting the economy by a shock that increases inflation expectations (positive shock) and by a shock that reduces inflation expectations (negative shock), alternatively. Since the VAR is by construction symmetric, any difference in the estimated parameters obtained using the model-IRFs to a positive and to a negative shock has to be due to the asymmetric effect of the shock. Table 5 reports the results on the estimated parameters. A negative shock to inflation expectations requires a higher degree of price rigidity, a lower degree of wage rigidity, no persistence of the shock, a lower response to inflation and a higher persistence in the Taylor rule.

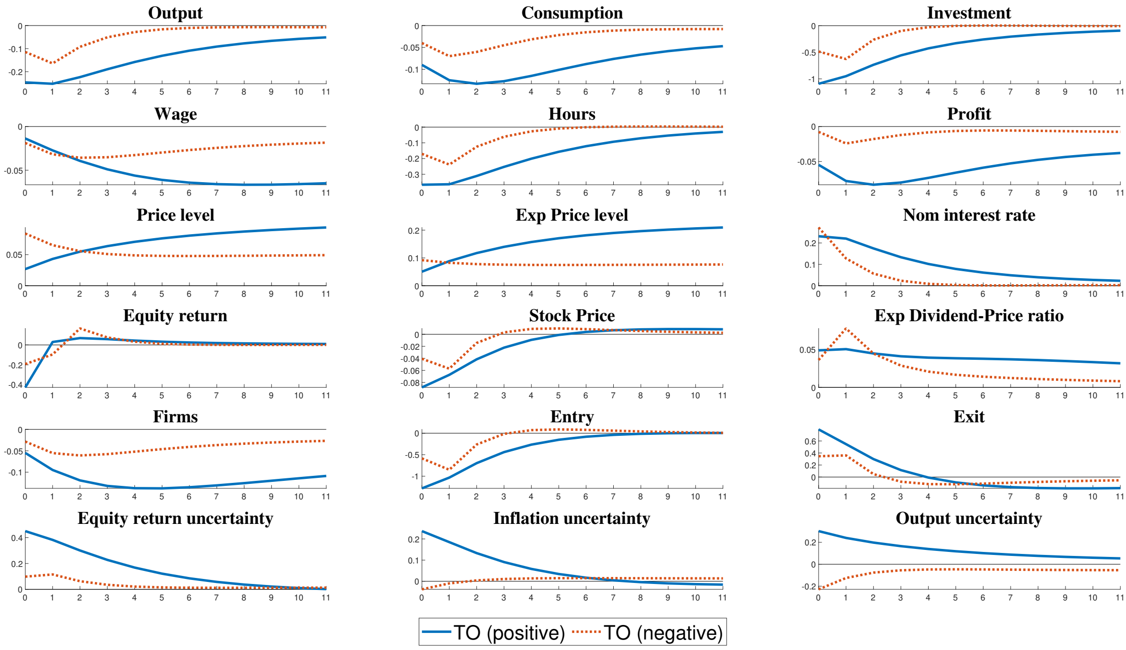

Figure 12: Re-estimating the model: positive (inflationary) versus negative (deflationary) inflation expectations shock (negative IRFs multiplied by -1.)

Figure 12 shows the implied IRFs to an one percent exogenous increase in inflation expectations (blu solid lines) and to an one percent exogenous decrease in inflation expectations (purple dashed lines) obtained using the parameters estimated in Table 5. As before, for a easier comparison between the two types of IRFs, the IRFs corresponding to a negative inflation expectation shock are multiplied by -1. Notice that as before the positive inflation expectations shock has stronger effects than the negative one. Moreover, the responses of inflation and output uncertainty have the opposite sign.

7.3 Local Projection with Positive and Negative shock

A natural step-ahead in the investigation of the asymmetric effect of the shock is to project negative and positive shock to our main macroeconomic variables and investigate whether there are significant asymmetric effects in the response of these variables. In particular, we test the asymmetric effects of inflation expectations shocks in data through local projection analysis once we retrieve the structural shock estimated in the linear VAR model in Section 5. We start our analysis with a sanity check of the VAR estimates. We regress the same variables employed in the VAR model over the estimated shocks. We run linear local projections as in Jordà (2005) and regress the following equation,

$$y_{t+h} = \alpha + \tau t + \delta t^2 + \beta_h \varepsilon_t + \gamma' \mathbf{x_t} + u_t, \tag{26}$$

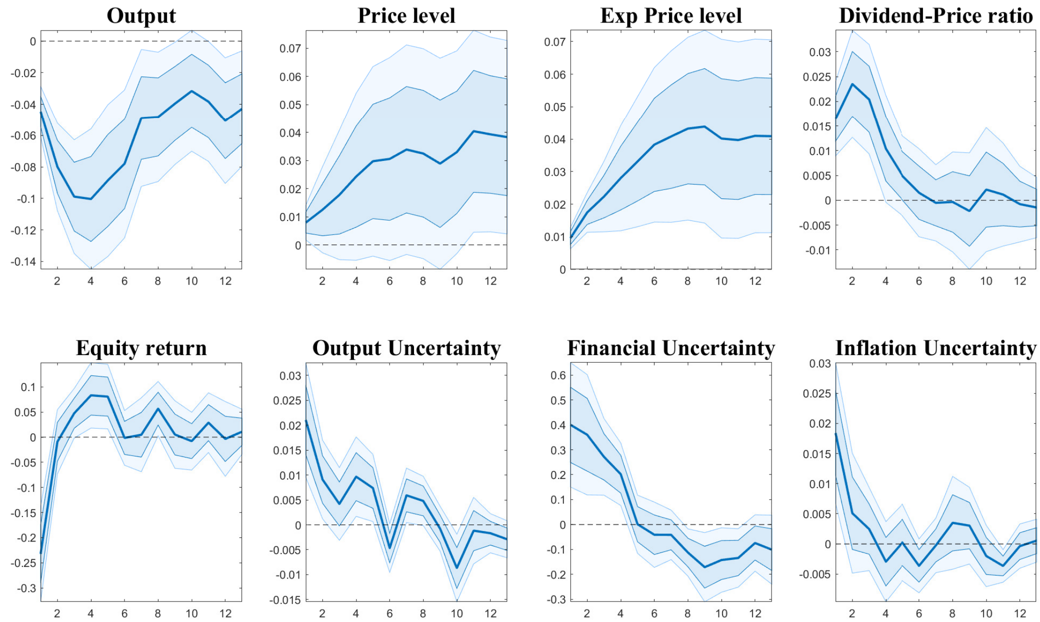

Figure 13: Linear model: IRFs to inflation expectations shock that increases inflation expectations by 1%.

where y_t is, alternatively, real GDP, one-quarter ahead forecast of GDP deflator, GDP deflator, equity return, dividend-to-price ratio, VXO, one-quarter ahead forecast dispersion of real GDP, and 1-q ahead forecast Dispersion of GDP deflator. We regress the dependent variable over a constant, a quadratic trend, the estimated inflation expectation shock ε_t, and $\mathbf{x_t}$, the lagged variables in the linear VAR. We set two lags for the control variables. Figure 13 shows the impulse responses of an identified inflation expectations shock that generates an initial one percentage point rise in the expected GDP deflator growth rate —i.e., h is on the x-axis, and β_h is on the y-axis. The patterns of the variables in Figure 13 confirm the transmission of the shock in the VAR impulse response and provide robustness for the latter. The inflation expectation shock is recessionary and inflationary. Dividend to price ratio and equity return respond at the opposite and the positive impact to the dividend-price ratio lasts more than the drop in the equity return. All the uncertainty measures increase but only for the financial uncertainty the response is still positive after a year from the shock. The second test we conduct is to regress other macroeconomic variables over the identified shock and check if the transmission is in line with our DSGE model. Specifically, we run the same regression as (26), but take as a dependent variable the logarithm of consumption (PCECC96), investment (GPDIC1), total hours (HOANBS), and net entry. The retrieved the data on the first three variables from the (FRED-QD database), while the measure of net entry is taken from Lewis and Winkler (2017). Remarkably, the impulse

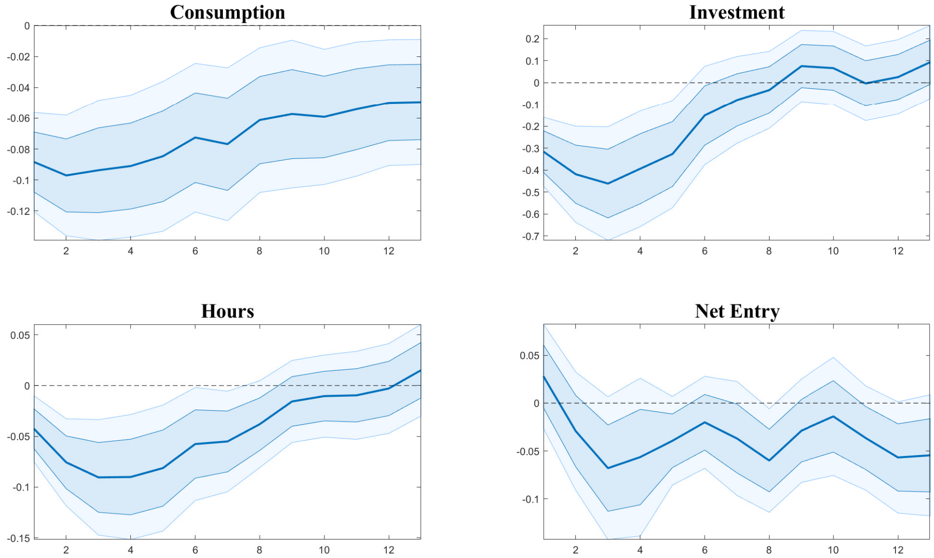

Figure 14: Linear model: IRFs to inflation expectation shocks that increases inflation expectations by 1%.

responses in Figure 14 show that the detrimental effect of the inflation expectation shock is confirmed when one looks at the dynamics of other real variables. Consumption, investment in physical capital, and total hours decline on impact, consistently with the DSGE model. The response of net entry is uncertain on impact, but becomes persistently negative afterwards, as in the model. Therefore, even expanding the analysis to other variables, the empirical findings confirm the detrimental effect of increased inflation expectations for the economic activity. Lastly, we test the asymmetric effects of inflation expectation shocks. In this respect, we follow Tenreyro and Thwaites (2016) and estimate the sequence of local projections:

$$y_{t+h} = \alpha + \tau t + \delta t^2 + \beta_h^+ \max\left[0, \varepsilon_t\right] + \beta_h^- \min\left[0, \varepsilon_t\right] + \gamma' \mathbf{x_t} + u_t, \tag{27}$$

where $\left[\beta_h^+, \beta_h^-\right]$, with $h \in [0, H]$, are the estimated coefficients associated with respectively, the positive and negative realization of inflation expectation shocks. Figure 15 reports the estimates of the local projections (27) of GDP, price level and the two variables we employ to distinguish between inflation expectation and supply shocks, that is the price-to-dividend ratio and output uncertainty. The IRFs are scaled so that the shock results in an one percentage point increase in the inflation expectations in all regimes. The first column of Figure 15 displays the estimates of the linear model, where the coefficient is restricted to be constant across shock realizations. The second and third columns display the 90 percent confidence intervals of the response to increasing inflation expectation shocks, and

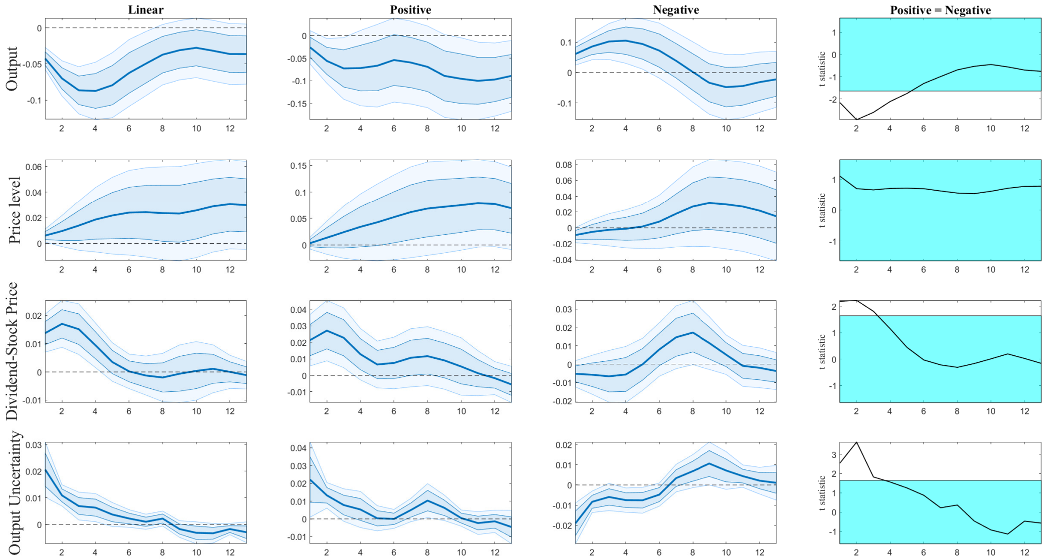

Figure 15: Linear model, increasing expectations, decreasing expectations: IRFs to inflation expectation shocks that impacts the inflation expectations by 1%. T-statistics tests the hypothesis of no differences between coefficients (Tenreyro and Thwaites, 2016).

decreasing inflation expectation shocks, respectively. The plots in the fourth column represent the estimates of the t-statistic of the null hypothesis that $(\beta_h^+ - \beta_h^-) = 0$, with the area between ± 1.65 shaded. So, if the solid line in the fourth column falls below the lower extreme of the area at some horizon h, we can reject the null that the IRFs at that horizon are equal in favor of the alternative that they are more negative after increasing inflation expectation shocks at a 10 percent significance level. Equally, if the solid line in the fourth column falls above the upper extreme of the area at some horizon h, we can reject the null hypothesis at that horizon in favor of the alternative that IRFs are more positive after increasing inflation expectation shocks. Figure 15 shows that the IRFs to increasing and decreasing inflation expectation shocks are statistically different for all variables but the price level. The negative effects of inflation expectation shocks for output, dividend-to-price ratio, and output uncertainty are larger - in absolute value- when shocks increase inflation expectations.

8 Conclusions

What is the macroeconomic impact of a shock that increases short-term inflation expectations? A the third order solution of a medium scale DSGE model characterised by endogenous firm entry and exit shows that shocks that increase inflation expectations are stagflationary causing a drop in output and an increase in inflation, as well as an endogenous increase in uncertainty of output and inflation. The increase in uncertainty amplifies the recessionary effect of the shock.

The DSGE model provides robust sign restrictions to impose in the identification of an inflation expectations shock in the empirical VAR, combined with a narrative sign restriction. The VAR-IRFs are then used to estimate the model parameters using limited information impulse response matching techniques, using alternatively the first-order and the third-order solution of the theoretical model. The estimated parameters obtained using the third-order solution of the model generate theoretical IRFs that are closer to the empirical ones than those obtained estimating the first-order solution of the model, thus confirming the importance of endogenous uncertainty. The third-order approximation of the Baseline model requires a substantially lower degree of price rigidity and a larger degree of wage rigidity. Last, but not least, the model economy shows the existence of asymmetric effect in the transmission of inflation expectations shocks. Shocks that increase inflation expectations imply a stronger effect on the main real variables than shocks that reduce inflation expectations.

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Appendix

This Appendix comprises three Sections. Section A shows: (i) the VAR-IRFs to a supply shock in Section A.1; (ii) the forecast error variance decomposition of the variables with respect to the inflation expectation shock and the supply shock in Section A.2; (iii) the time series of the structural shocks in Section A.3; (iv) a series of robustness checks on the VAR analysis regarding alternative samples, priors and trends specifications. Section B shows the list of the equations of the DSGE model. Section C displays the IRFs of the VAR estimated on data generated from the third-order solution of the DSGE model and compares them to the DSGE-IRFs.

A VAR Analysis

A.1 Impulse Response Functions to a Supply Shock

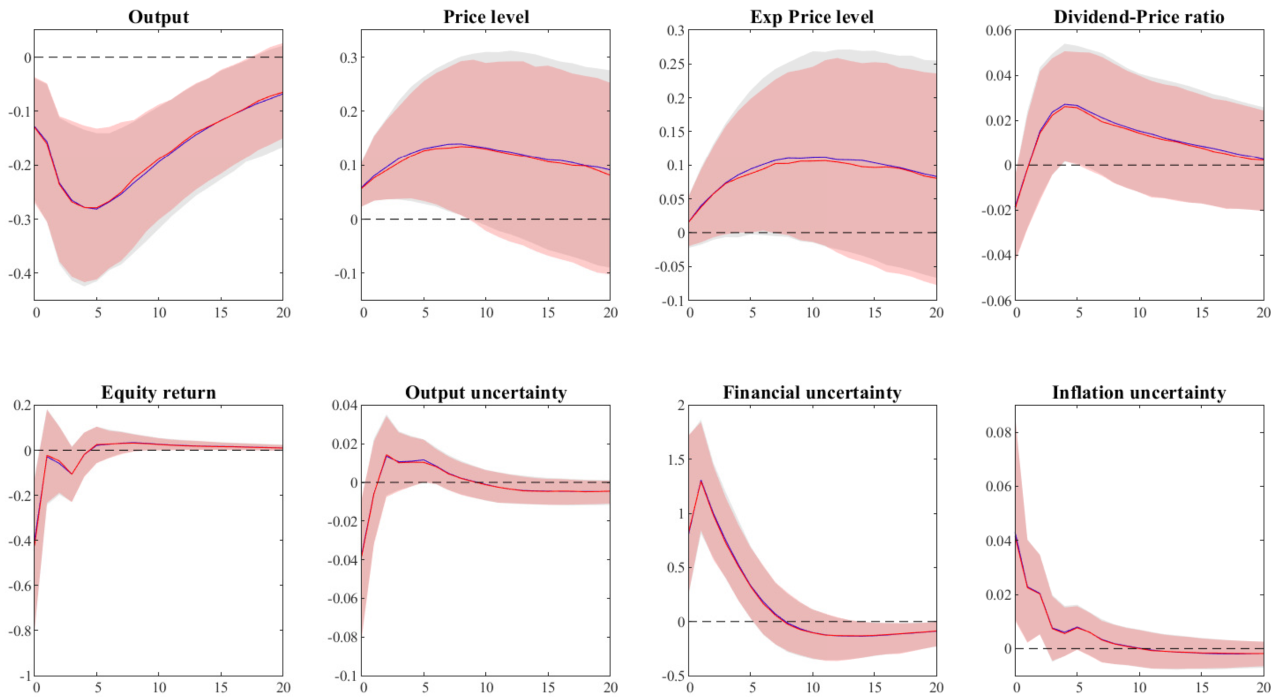

Figure 16: VAR impulse response functions to **supply shock** (68% percentile): in grey the estimated IRFs obtained using only sign restrictions, in red the estimated IRFs obtained using sign restrictions and the narrative.

A.2 Forecast Error Variance Decomposition

Variable	Horizon	Inflation Exp. shock	Supply shock
Output	1	0.08	0.04
	4	0.26	0.10
	20	0.21	0.12
Price Level	1	0.04	0.06
	4	0.04	0.04
	20	0.05	0.03
Exp. Price level	1	0.11	0.06
	4	0.09	0.05
	20	0.05	0.03
Dividend-Price	1	0.13	0.03
	4	0.14	0.03
	20	0.14	0.04
Equity Return	1	0.18	0.01
	4	0.17	0.03
	20	0.14	0.04
Output Uncertainty	1	0.17	0.03
	4	0.18	0.04
	20	0.18	0.05
Financial Uncertainty	1	0.13	0.03
	4	0.15	0.11
	20	0.16	0.10
Inflation Uncertainty	1	0.11	0.03
	4	0.11	0.05
	20	0.11	0.06

Table 6: Forecast error variance decomposition: relative contribution of inflation expectation shocks and supply shock identified using sign restrictions and the narrative.

A.3 Structural shocks

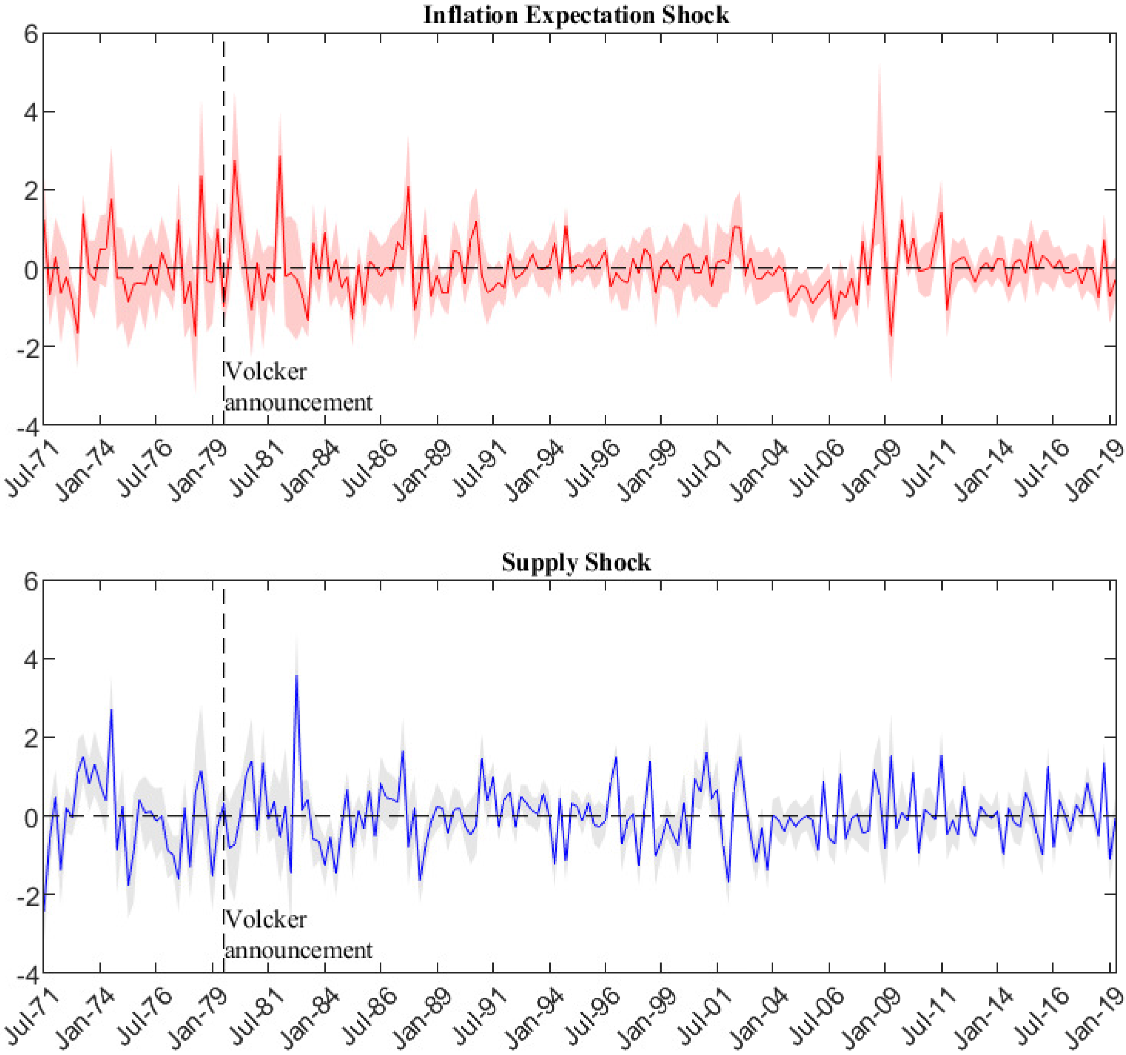

Figure 17: Estimated structural shocks: inflation expectation shocks and supply shock identified using sign restrictions and the narrative.

A.4 Robustness checks

This Section presents several robustness checks. First, we show the results of our VAR using the same sample considered in the main text, but using alternative priors and alternatives trends specifications (see Figures 18-22). Second, we report the IRFs obtained using two alternative samples. Specifically, we consider a sample starting in 1985:q1 and ending in 2019:q2 (see Figures 23 and 24 for the inflation expectations shock and the supply shock respectively), which thus excludes the effects of the oil shock and hyperinflation period. Then, we consider a sample starting in 1971:q1 and ending in 2007:q4, that is excluding the last great recession (see Figures 25 and 26 for the inflation expectations shock and the supply shock respectively).

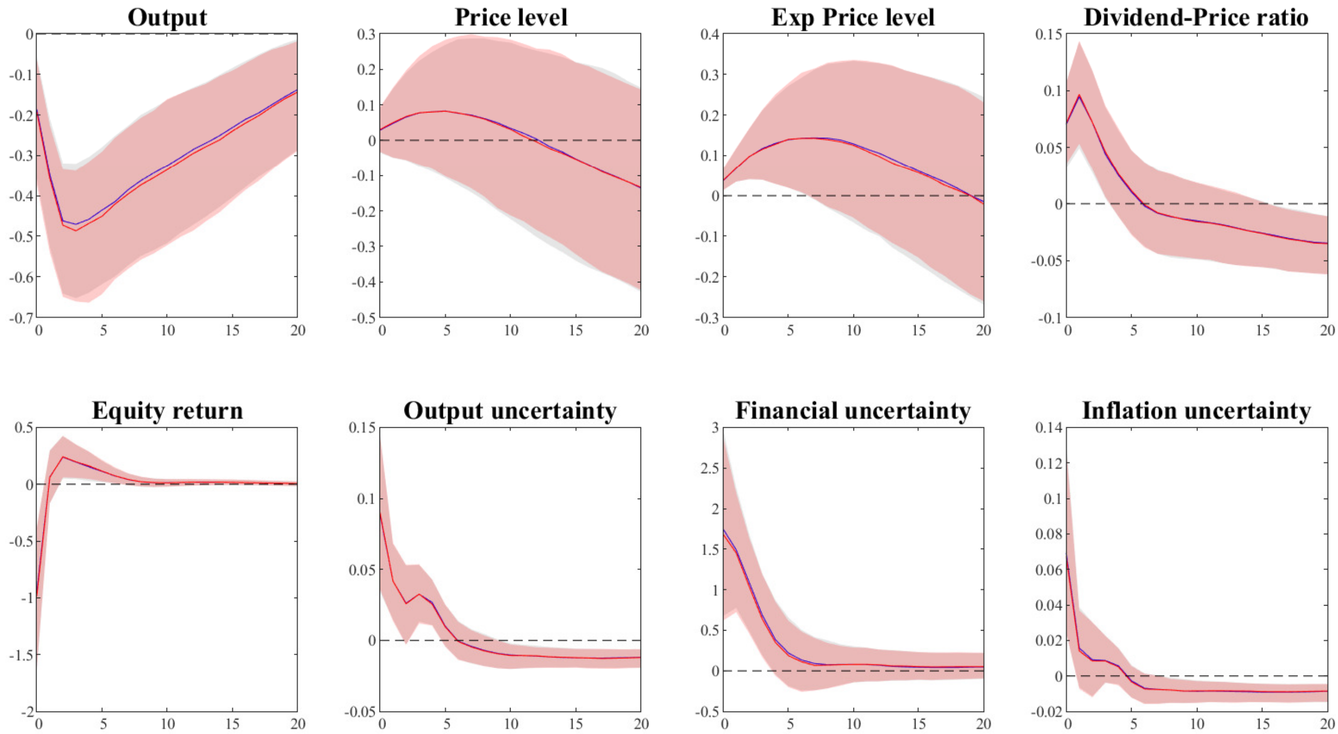

Figure 18: VAR impulse response functions to an **inflation expectation shock** (68% percentile): in grey the estimated IRFs obtained using only sign restrictions, in red the estimated IRFs obtained using sign restrictions and the narrative. VAR specification without trend.

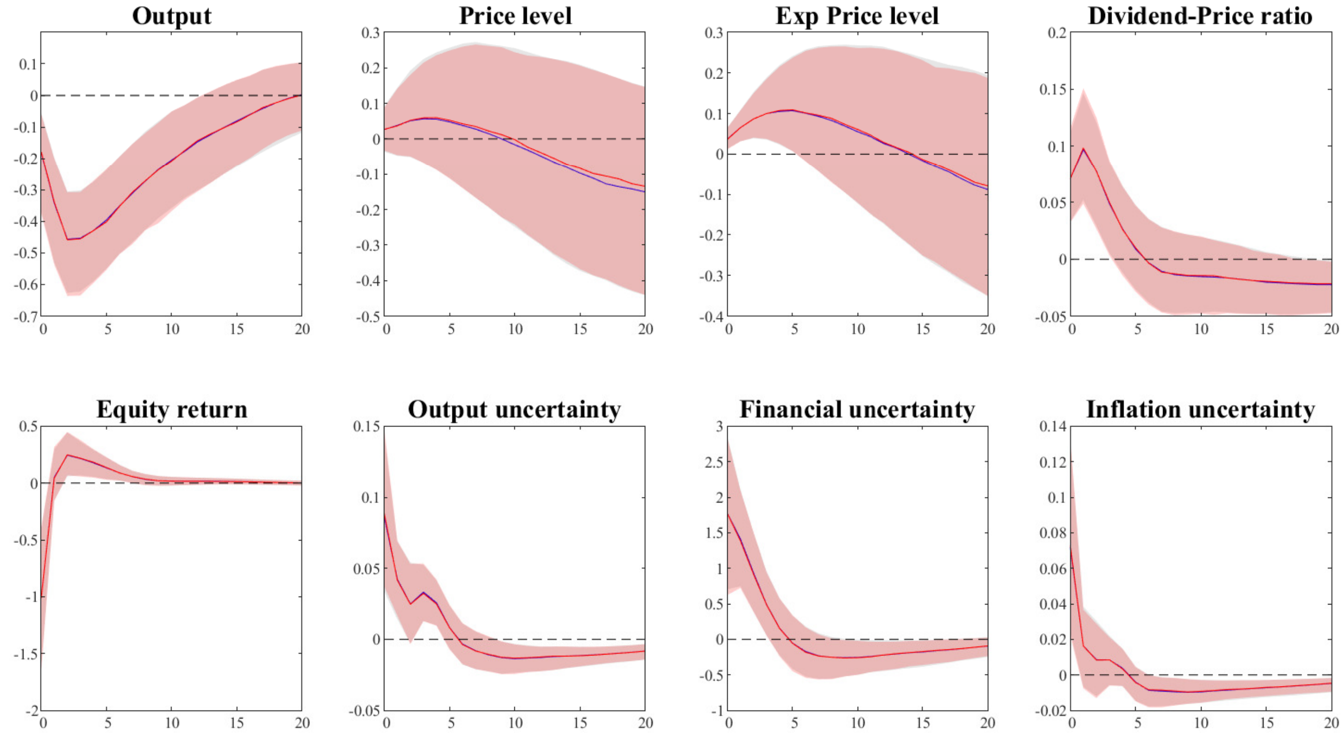

Figure 19: VAR impulse response functions to an **inflation expectation shock** (68% percentile): in grey the estimated IRFs obtained using only sign restrictions, in red the estimated IRFs obtained using sign restrictions and the narrative. VAR specification with linear trend.

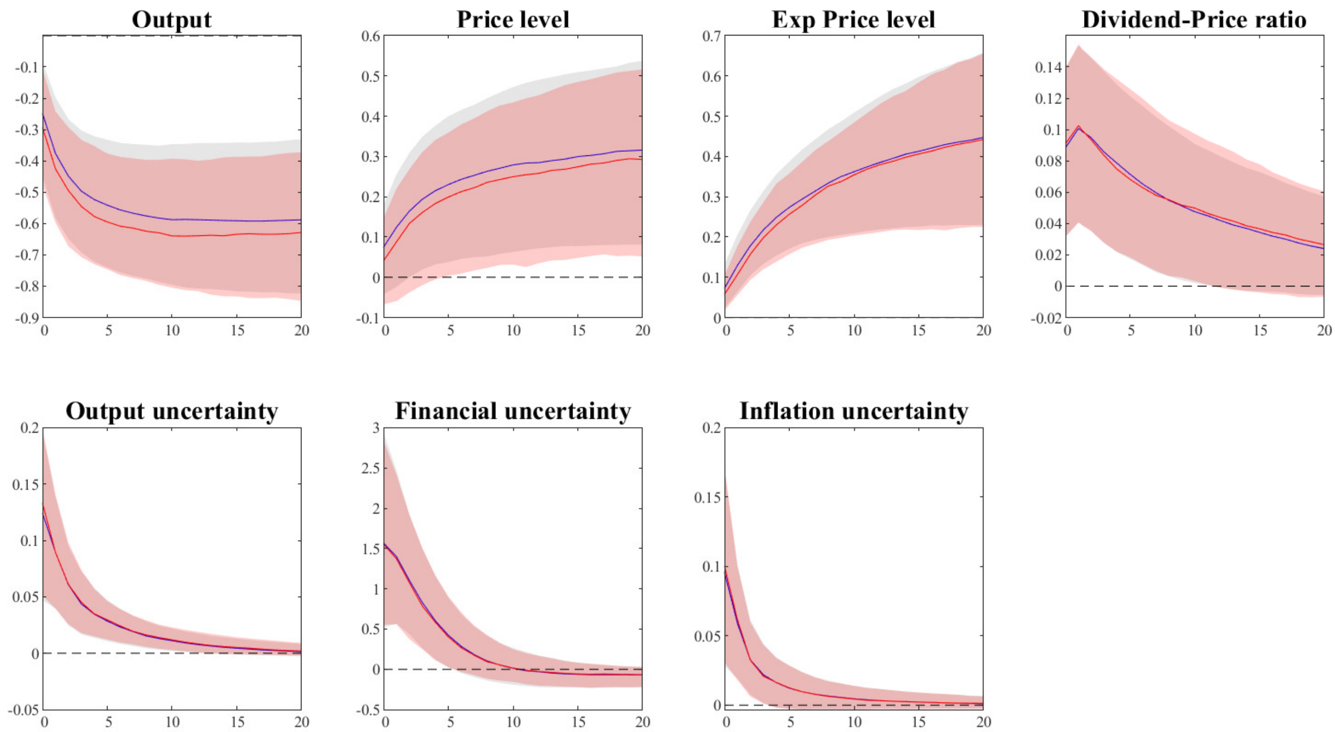

Figure 20: Dynamic responses to inflation expectations shock. **Informative priors. No trend specification**

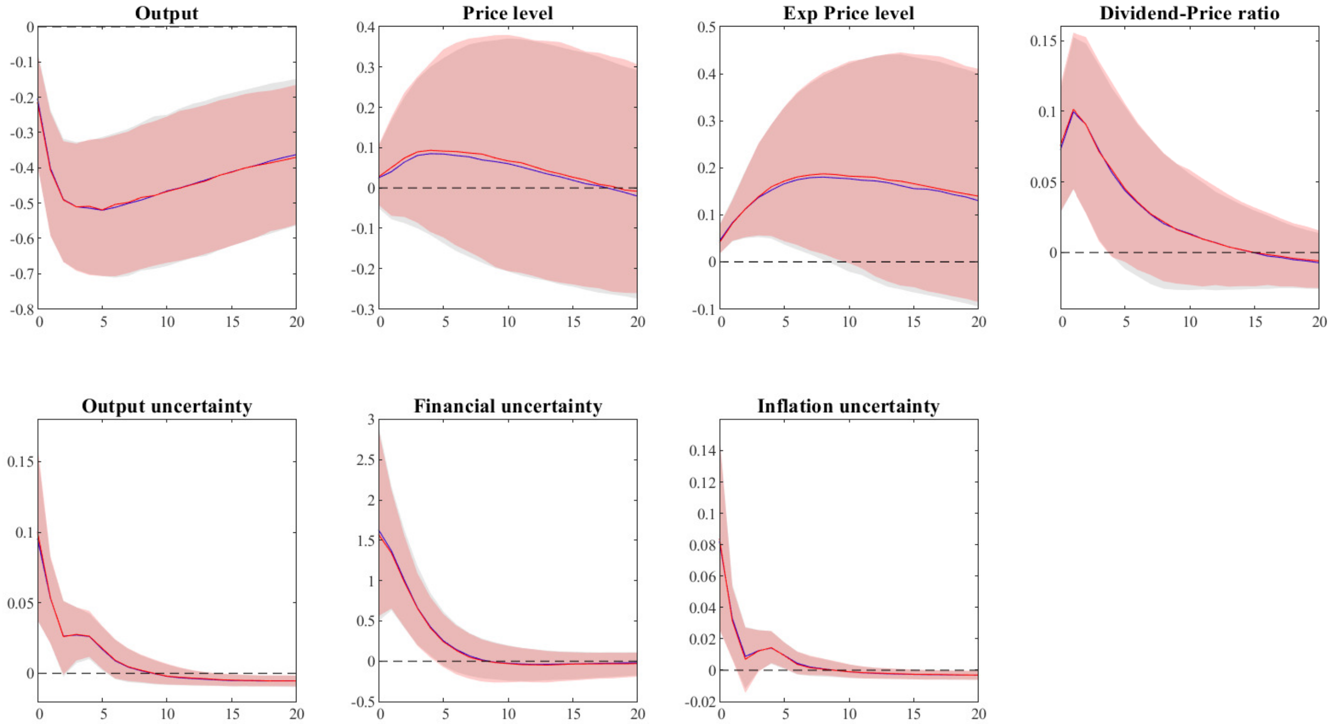

Figure 21: Dynamic responses to inflation expectations shock. **Weak priors. No trend specification**

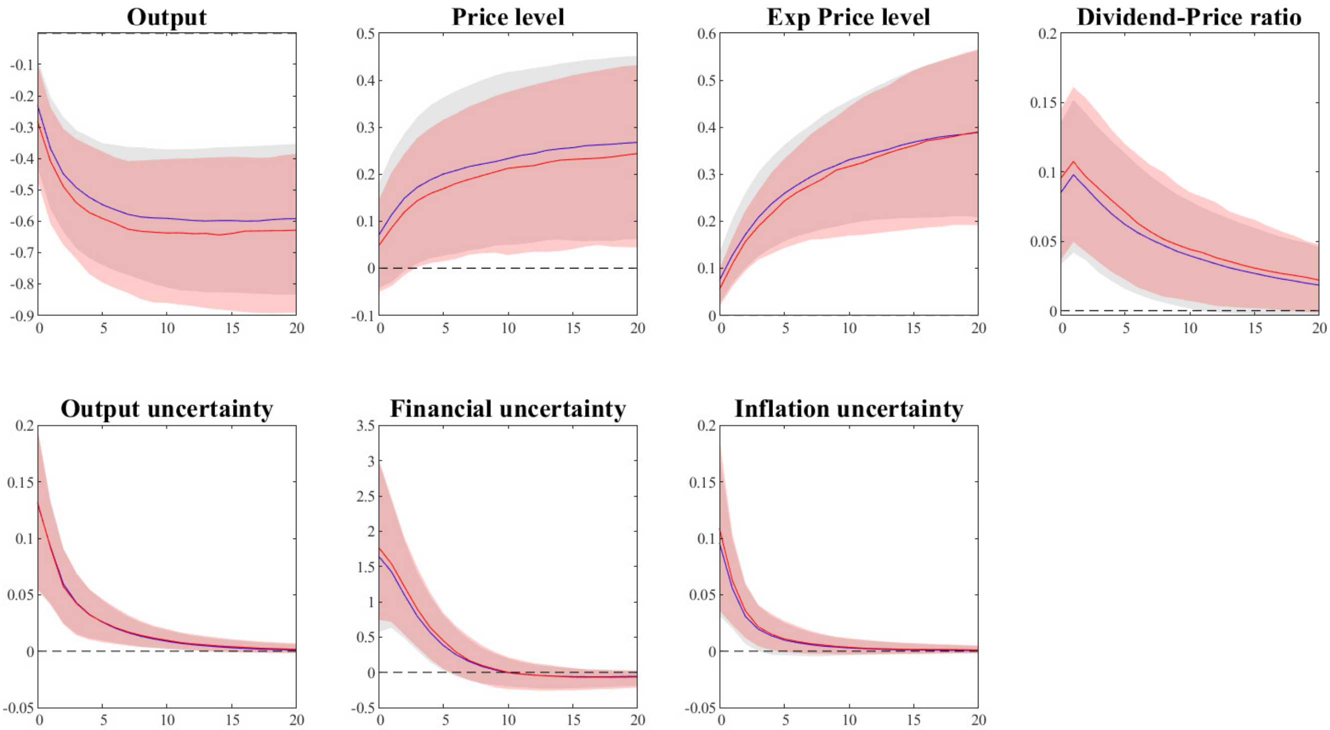

Figure 22: Dynamic responses to inflation expectations shock. **Informative priors. Quadratic specification**

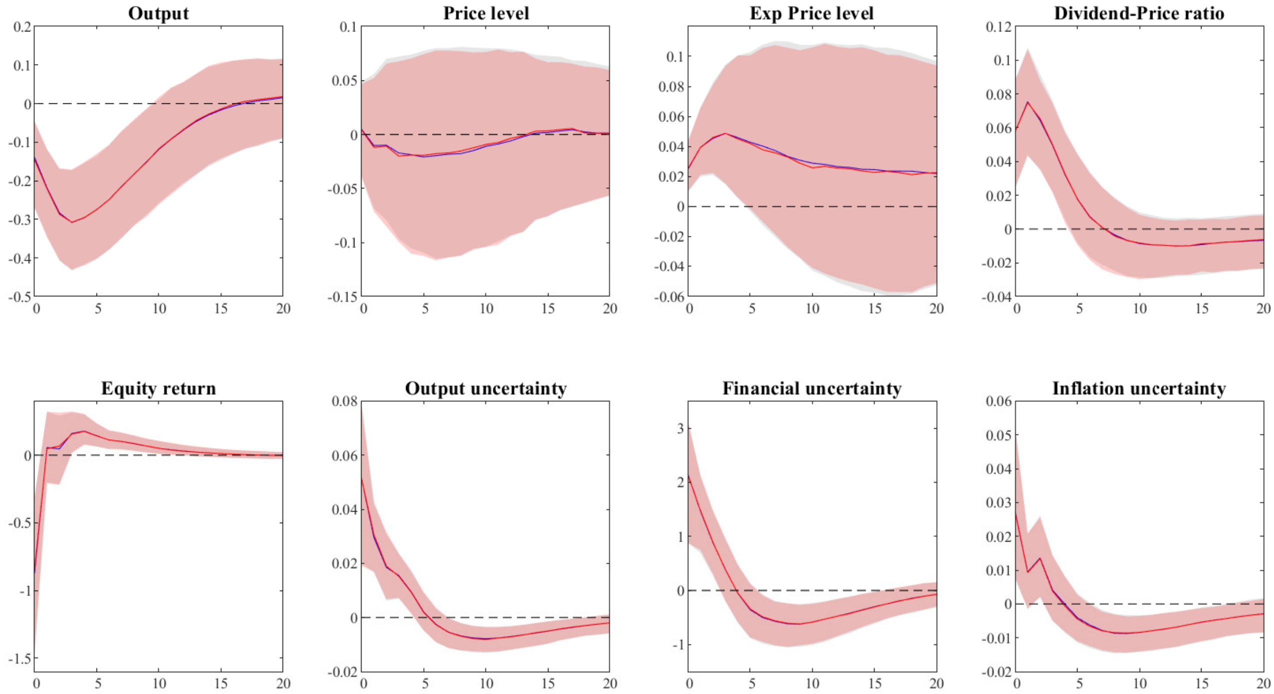

Figure 23: Sample period 1985:q1-2019:q2. VAR responses to **inflation expectation shock** (68% percentile): in grey only sign restrictions, in red sign restrictions plus narrative

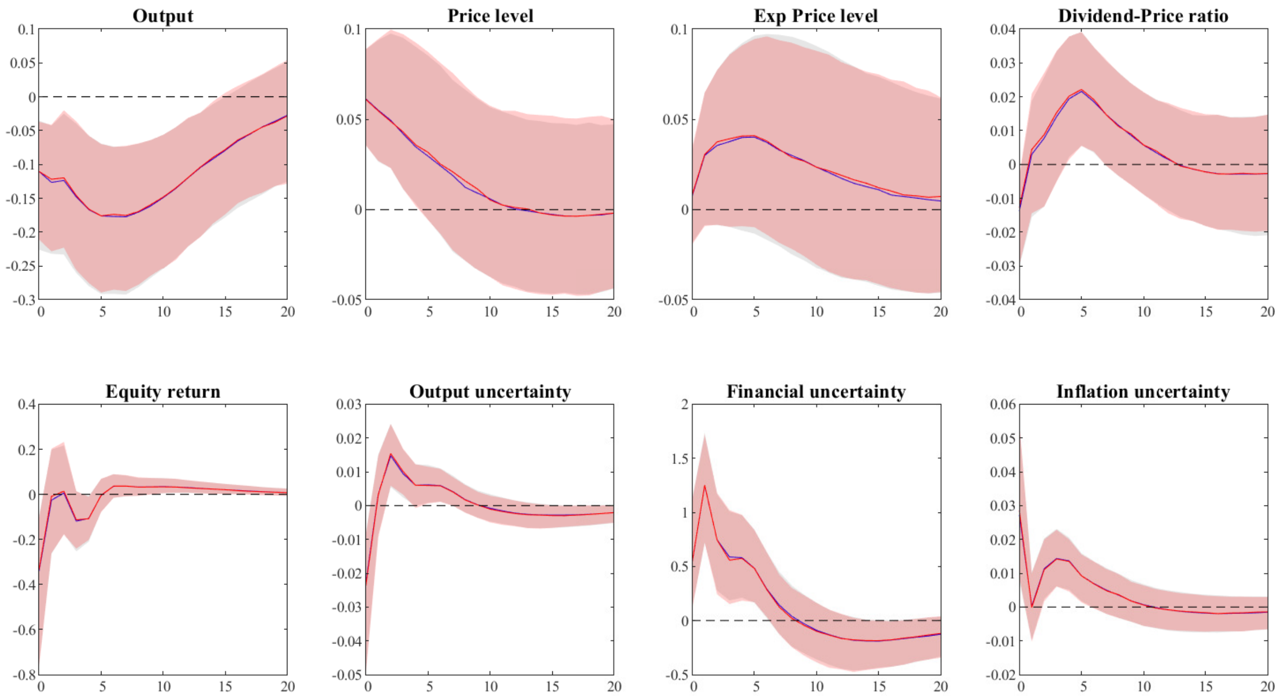

Figure 24: Sample period 1985:q1-2019:q2. VAR responses to **supply shock** (68% percentile): in grey only sign restrictions, in red sign restrictions plus narrative

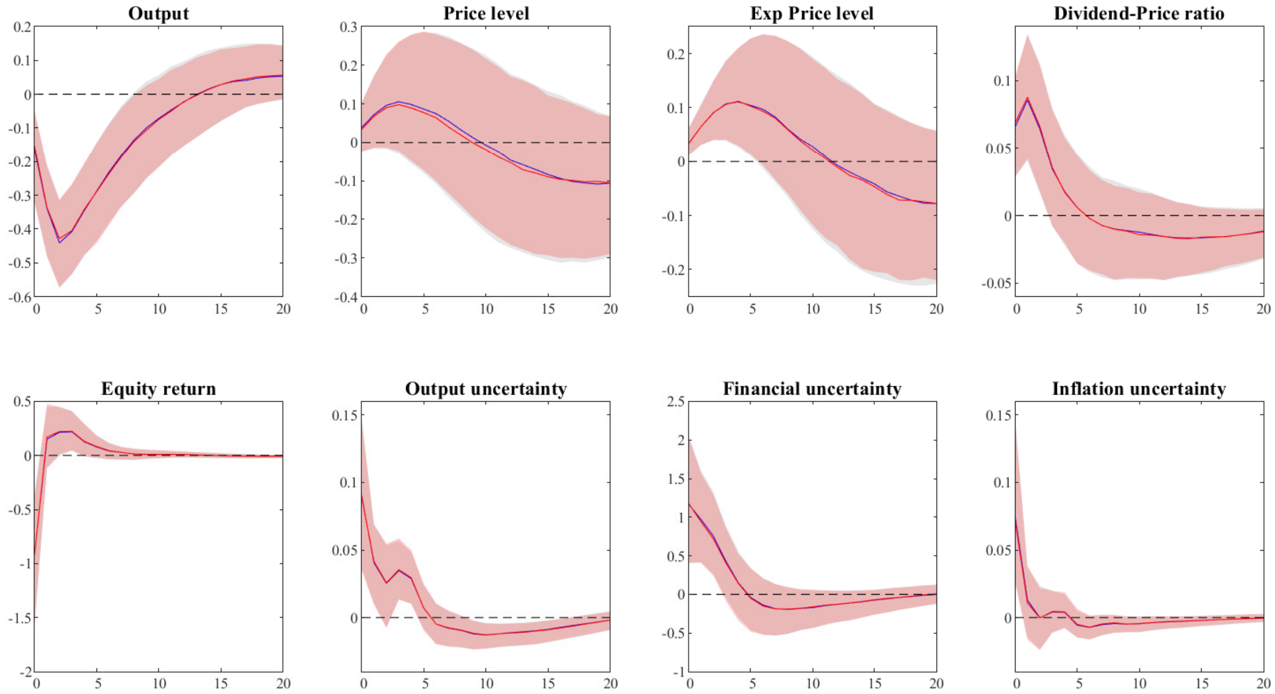

Figure 25: Sample period 1971:q1-2007:q4. VAR responses to **inflation expectation shock** (68% percentile): in grey only sign restrictions, in red sign restrictions plus narrative

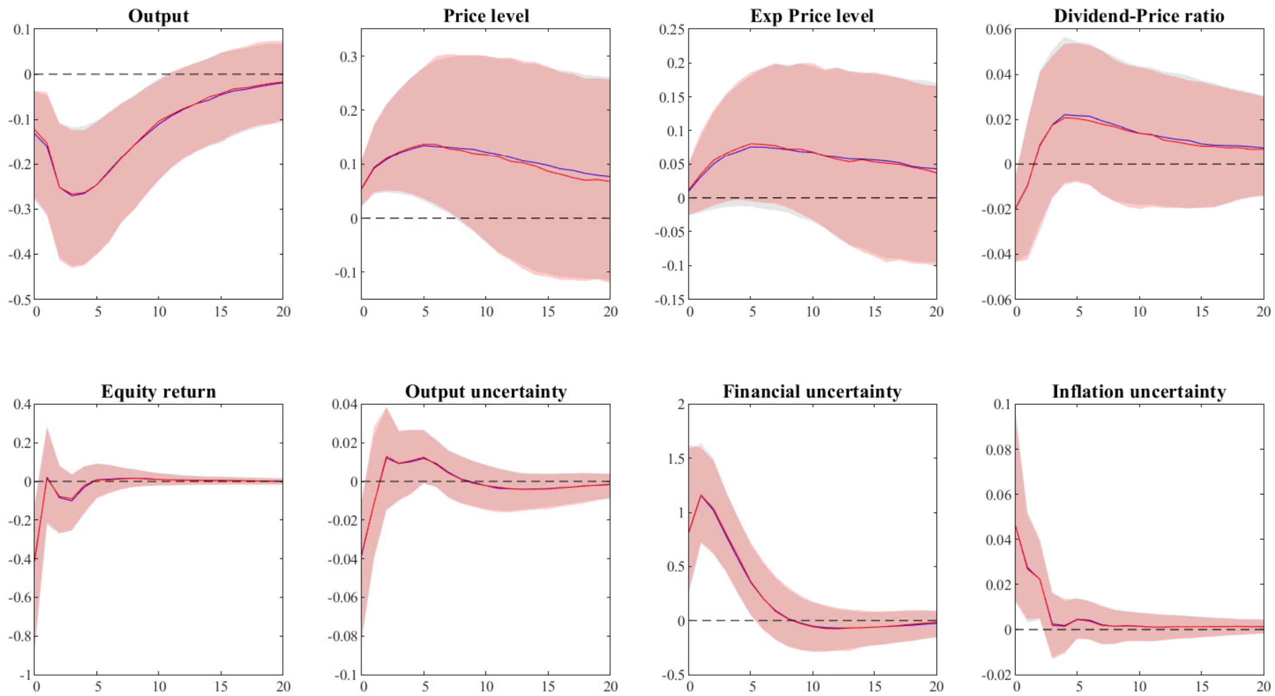

Figure 26: Sample period 1971:q1-2007:q4. VAR responses to **supply shock** (68% percentile): in grey only sign restrictions, in red sign restrictions plus narrative

B List of Equations DSGE model

The system of non-linear equation is summarized in the Tables below.

	Description	Equations
1)	Marginal utility of consumption	$\lambda_t = \left(C_t - h\bar{C}_{t-1}\right)^{-\sigma_C} \exp\left(\chi \frac{(\sigma_C - 1)(L_t)^{1+\sigma_L}}{1+\sigma_L}\right),$
2)	Marginal rate of substitution	$mrs_t = \chi\left(C_t - h\bar{C}_{t-1}\right)(L_t)^{\sigma_L},$
3)	Law of motion of capital	$K_{t+1} = (1 - \delta^K - \frac{\phi_K}{2}\left(\frac{I_t}{K_t} - 1\right)^2)K_t + I_t,$
4)	Euler equation	$\lambda_t = \beta E_t\left[\lambda_{t+1}(1+r_t)\right],$
5)	Euler equation for incumbent firm	$v_t(\widetilde{z}_t) = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left((1-\eta_{t+1})\left(v_{t+1}(\widetilde{z}_{t+1}) + j_{t+1}(\widetilde{z}_{t+1})\right) + \eta_{t+1} l v_{t+1}\right)\right],$
6)	Euler equation for entrant firm	$v_t(\widetilde{z}_t) = f^E + ec_t,$
7)	Euler equation for capital	$\psi_t = \beta E_t\left[\begin{array}{c}\lambda_{t+1}\left(r^K_{t+1}u_{t+1} - a(u_{t+1})\right) + \psi_{t+1}(1-\delta_K) \\ -\psi_{t+1}\left(\frac{\phi_K}{2}\left(\frac{I_{t+1}}{K_{t+1}} - \delta^K\right)^2 - \phi_K\left(\frac{I_{t+1}}{K_{t+1}} - \delta^K\right)\frac{I_{t+1}}{K_{t+1}}\right)\end{array}\right],$
8)	Euler equation for investments	$1 = q_t\left(1 - \phi_K\left(\frac{I_t}{K_t} - \delta^K\right)\right),$
9)	Tobin q	$q_t = \frac{\psi_t}{\lambda_t},$
10)	FOC variable capital utilization	$r^k_t = \gamma_1 + \gamma_2(u_t - 1),$
11)	Variable capital utilization adj. costs	$a(u_t) = \gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2,$
12)	Law of motion of firms	$N_t = (1-\eta_t)\left(N_{t-1} + N^E_{t-1}\right),$
13)	Wage NKPC	$1 = \frac{\theta_w}{\theta_w - 1}\frac{mrs_t}{w_t} - \frac{\phi_w}{\theta_w - 1}(\pi^w_t - 1)\pi_t\frac{Y_t}{w_{t-1}L_t} + \frac{\phi_w}{\theta_w - 1}E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\pi^w_{t+1} - 1\right)\pi^w_{t+1}\frac{Y_{t+1}}{w_t L_t}\right],$
14)	Wage inflation	$\pi^w_t = \frac{w_t}{w_{t-1}}\pi_t,$
15)	Wage adj. costs	$WAC_t = \frac{\phi_w}{2}(\pi^w_t - 1)^2 Y_t,$

Table 7: System of non-linear equations

	Description	Equations
16)	Price NKPC	$1 = \frac{\theta_p}{\theta_p - 1}\rho_t^I - \frac{\phi_p}{\theta_p - 1}(\pi_t - 1)\pi_t + \frac{\phi_p}{2}(\pi_t - 1)^2 + \frac{\phi_p}{\theta_p - 1}E_t\left[\Lambda_{t,t+1}(\pi_{t+1} - 1)\pi_{t+1}\frac{Y_{t+1}}{Y_t}\right],$
17)	Love of variety equation	$\tilde{\rho}_t = N_t^{\frac{1}{\theta_p - 1}}\rho_t^I,$
18)	Stochastic discount factor	$\Lambda_{t,t+1} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(1 - \eta_{t+1})\right],$
19)	Entry congestion externalities	$ec_t = \Theta^e\left(\frac{N_t^E}{N_t}\right)^{\varsigma_e},$
20)	Exit congestion externalities	$xc_t = \Theta^x\left(\frac{N_t^X}{N_t}\right)^{\varsigma_x},$
21)	Exiting firms	$N_t^X = \eta_t\left(N_{t-1} + N_{t-1}^E\right),$
22)	Liquidation value	$lv_t = (1 - \tau)f^E - xc_t,$
23)	Exit probability	$\eta_t = 1 - \left(\frac{z_{\min}}{\bar{z}_t}\right)^{\xi},$
24)	Average productivity	$\tilde{z}_t = \left(\frac{\xi}{\xi + 1 - \theta_p}\right)^{\frac{1}{\theta_p - 1}}\bar{z}_t,$
25)	Value of the marginal firm	$v_t(\bar{z}_t) = j_t(\bar{z}_t) + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(1 - \eta_{t+1})v_{t+1}(\bar{z}_{t+1})\right],$
26)	Exit condition	$v_t(\bar{z}_t) = lv_t,$
27)	Profits of the marginal firm	$j_t(\bar{z}_t) = \left(\frac{\theta_p}{\theta_p - 1} - 1\right)mc_t(\widetilde{z}_t)\left(\frac{\bar{z}_t}{\tilde{z}_t}\right)^{1-\theta_p}y_t(\widetilde{z}_t),$
28)	Optimal price of the average firm	$\tilde{\rho}_t = \mu mc_t(\widetilde{z}_t),$
29)	Mark-up of the intermediate firm	$\mu = \frac{\theta_p}{\theta_p - 1},$
30)	Profits of the average firm	$j_t(\widetilde{z}_t) = N_t^{-1}\left(Y_t - w_tL_t - r_t^kK_t^s\right),$

Table 8: System of non-linear equations

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	Description	Equations
31)	Labor demand	$w_t = \tilde{z}_t mc_t \left(\widetilde{z}_t\right) \left(1-\alpha\right) \left(\frac{L_t}{K_t^s}\right)^{-\alpha},$
32)	Capital service demand	$r_t^K = \tilde{z}_t mc_t \left(\widetilde{z}_t\right) \alpha \left(\frac{L_t}{K_t^s}\right)^{1-\alpha},$
33)	Output of the average firm	$y_t \left(\widetilde{z}_t\right) = \widetilde{z}_t \left(L_t\right)^{1-\alpha} \left(K_t^s\right)^{\alpha},$
34)	Capital-capital service relation	$K_t^s = u_t K_t,$
35)	Aggregate output	$Y_t = N_t^{\frac{1}{\theta_p - 1}} \widetilde{z}_t \left(L_t\right)^{1-\alpha} \left(K_t^s\right)^{\alpha},$
36)	Aggregate resource constraint	$Y_t = C_t + I_t + a\left(u_t\right) K_t + N_t^E ec_t + N_t^X xc_t + PAC_t + WAC_t,$
37)	Price adj. costs	$PAC_t = \frac{\phi_p}{2} \left(\pi_t - 1\right)^2 Y_t,$
38)	Government budget constraint	$T_t = f^E N_t^E - \left(1-\tau\right) f^E N_t^X,$
39)	Taylor rule	$\left(\frac{1+i_t}{1+i}\right) = \left(\frac{1+i_{t-1}}{1+i}\right)^{\phi_R} \left(\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{\phi_{dy}}\right)^{(1-\phi_R)} e^{\varepsilon_{R,t}},$
40)	Fisher equation	$1 + i_t = \left(1 + r_t\right) E_t \left[\pi_{t+1}\right],$
41)	Monetary shock	$\varepsilon_{R,t} = \rho_R \varepsilon_{R,t-1} + e^{\sigma_{R,t}} u_{\varepsilon,t},$
42)	Uncertainty shock	$\sigma_{R,t} = \left(1-\rho_\sigma\right) \sigma_R + \rho_\sigma \sigma_{R,t-1} + u_{\sigma,t},$

Table 9: System of non-linear equations

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C VAR on Simulated Data from the Third-Order solution of the DSGE Model

We choose a linear VAR as our data counterpart and sign restrictions based on Montecarlo simulations of the DSGE model to identify structural shocks. However, Montecarlo simulations come from an inflation expectation shock only using a non-linear DSGE model approximated at the third order. To address the possible tension between our non-linear model and the linear VAR, here we show that, conditional on our non-linear DSGE model being the data generating process, the VAR specification is able to obtain the true impulse responses to an inflation expectations shock. We proceed in two steps. First, we simulate a sample of 10,000 observations (of which 2000 used as burn in) with the DSGE model conditional on the calibration we used in Section 3 of the main text. Second, we use the simulated series and sign restrictions suggested by the Montecarlo exercise in the main text for estimating an inflation expectation shock. Figure 27 compares the DSGE-based impulse response with the VAR-based ones obtained with simulated data. We consider the traditional impulse response functions in percent deviation from the stochastic steady as in Fernández-Villaverde et al. (2015) and simulation-based impulse responses in deviations from the ergodic mean of the endogenous variables similar to the generalized impulse responses of Koop et al. (1996).[13] VAR-based impulse response functions obtained with simulated data closely follow the DSGE-based ones. This corroborate our choice for the empirical methodology. The VAR is successful at recovering the true impulse responses from the model.

[13]We use Dynare version 4.4.3 to solve and simulate data and impulse response functions from the DSGE model.

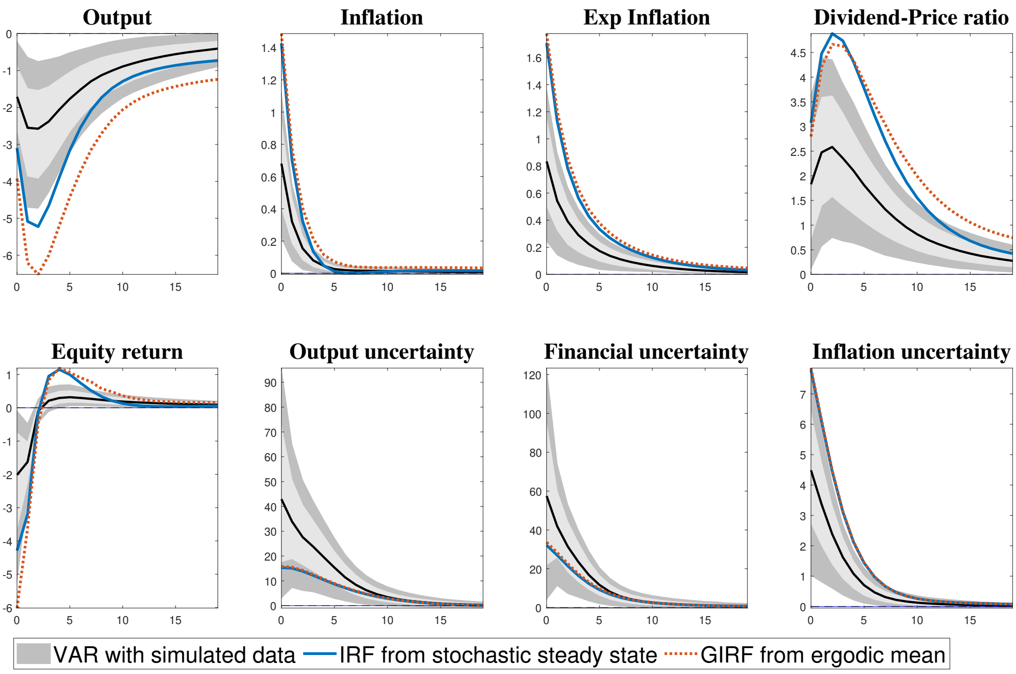

Figure 27: Dynamic responses to an inflation expectations shock. VAR using simulated data. 95% percentile in grey area, median in black solid line. DSGE-model IRFs (blu dotted line), DSGE-model GIRFs (red dotted line)