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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 firm dynamics for the transmission mechanism of an inflation expectations shock. Furthermore, shocks that increase inflation expectations have stronger effects than shocks that reduce inflation expectations.

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 convincingly 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). 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

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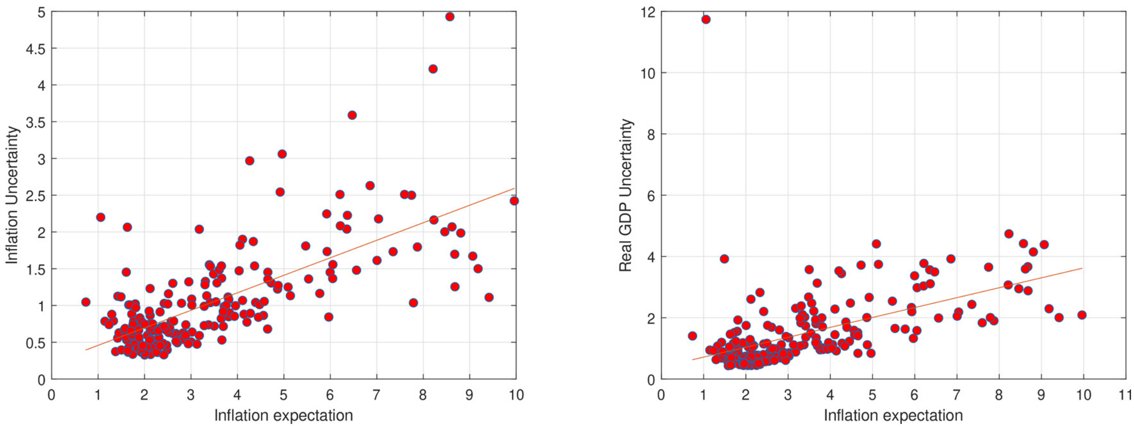

Fig. 1. Left: Mean one-quarter ahead inflation expectations of the SPF and inflation uncertainty from the SPF, i.e., standard deviation of individual point forecasts on GDP price index growth rate. **Right**: Mean one-quarter ahead inflation expectations of the SPF and GDP uncertainty from the SPF, i.e.,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

such volatility.[1] While this literature naturally concentrates on explaining the survey micro data and understanding the formation, the determinants and the heterogeneity of inflation expectations, we take here a different and complementary approach, that is, a macroeconomic perspective. We want to assess what are the macroeconomic effects of an exogenous shock to short-term inflation expectations, that is, an exogenous deviation of inflation expectations from rationality. From a policy point of view, this wants also to capture what policy makers seem to have in mind in their speeches and discussions. Central banks and policy makers do monitor very closely the development of inflation expectations. They are worried about the possibility of inflation expectations getting out of control, as if policy had respond to counteract exogenous shifts of inflation expectations. That would not make sense if expectations are fully rational and endogenously internalize the policy reaction to fundamental shocks.

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.[2] This literature investigates, both empirically and theoretically, how news about future TFP (e.g., Barsky and Sims, 2011; 2012; Beaudry and Portier, 2006; 2014) or exogenous waves of optimism and pessimism due to sentiment (e.g., Angeletos et al., 2018; Benhabib et al., 2015) 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 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., Cogley et al., 2010; Haque, 2022; Ireland, 2007).

Through the lens of a rich DSGE model with firm dynamics, this paper answers the question at the outset about the macroeconomic impact of a shock that increases short-term inflation expectations. It shows 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.[3] We face a similar challenge to disentangle the inflation expectations 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 expectations 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.

Fig. 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

[1] 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).

[2] *"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).

[3] 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 Service of Professional Forecasters (SPF) and the latter is the standard deviation of their forecasts.[4] 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. Fig. 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 expectations 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 impulse response functions (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 causes an endogenous increase in output uncertainty, equity return uncertainty, and inflation uncertainty. The comparison between the first and third-order solution of the model reveals that the uncertainty channel amplifies the transmission of an inflation expectations shock inducing a further reduction in firms' net entry and economic activity.

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 show that while both an inflation expectations shock and a supply shock are inflationary and recessionary, they differ in the sign of the response of the expected dividend-price ratio and of output uncertainty. We then base our identification strategy on these different responses. 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 in Q3/1979 caused a negative shock on inflation expectations.

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.[5] The VAR analysis suggests that a shock that increases inflation expectations 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 expectations 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 IRFs matching techniques as in Christiano et al. (2005), Christiano et al. (2010), Mumtaz and Theodoridis (2020) and Fasani et al. (2023) among others. These parameters are first estimated using the model-IRFs generated by the third order solution of the theoretical 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 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 expectations 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 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

[4] 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.

[5] 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 model and with the typical definition of uncertainty.

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.[6]

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. 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. 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. 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. Finally, as we were revising this paper for publication, we came across a paper by Barrett and Adams (2022) that study exactly the same type of shock to short-run inflation expectation. Their paper, however, mainly focuses on the empirical identification of such a shock, reaching actually opposite empirical conclusions to ours.

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 3.3 runs Montecarlo exercise in the spirit of Canova and Paustian (2011) to find the necessary sign restrictions needed to identify an inflation expectations shock and to disentangle it from a standard supply shock. Section 4 uses the sign restrictions of the previous section to estimate a VAR and identify the inflation expectations shock. Section 5 estimates the model using the limited information impulse response matching techniques. Section 6 investigates the asymmetric effects of the shock. Section 7 concludes.

2. Theoretical model

In this Section, we describe the theoretical framework of the baseline model (labeled as Baseline henceforth). The Baseline model is a modified version of a standard medium-scale model considered by Fasani et al. (2023). We assume sticky nominal wages and prices as in Rotemberg (1982), adjustment costs and capacity utilization for capital, external habit persistence. The microfoundations of the main ingredients of a medium-scale model are well known in the literature (Christiano et al., 2005; Smets and Wouters, 2007), so the details are not discussed here. The following thus focuses on the two main differences between our Baseline model and a standard medium-scale model: (i) firm heterogeneity and endogenous entry and exit dynamics in the intermediate sector; (ii) the inflation expectations shock. The full list of the equations of the model is in the online 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 households' utility is defined over the Dixit-Stiglitz consumption bundle, C_t, and the labour bundle of services, L_t, as:[7]

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

where h measures the degree of external habits in consumption, $\overline{C}_{t-1}$ is the last period aggregate consumption, σ_C defines the relative risk aversion, χ the relative weight assigned to labour and $\sigma_L > 0$ the inverse of the Frisch elasticity of the labour supply.

[6] In the online Appendix, we also test asymmetric effects of inflation expectations shock through local projection and using the structural shock estimated in our linear VAR. We find 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.

[7] 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.

The household budget constraint is the following:

$$C_t + B_t + \upsilon_t(\tilde{z}_t)x_t + I_t + FEX_t N_t^E + T_t \leq w_t L_t + \left[r_t^K u_t - a(u_t)\right]K_t$$
$$+\frac{1+r_{t-1}}{1+\pi_t}B_{t-1} + +[(1-\eta_t)(\upsilon_t(\tilde{z}_t) + j_t(\tilde{z}_t)) + \eta_t l\upsilon_t]\left(x_{t-1} + N_{t-1}^E\right). \tag{2}$$

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. Hence, households own physical capital stocks, K_t, and lease capital services, K_t^s, to firms. Capital services are related to the physical capital according to $K_t^s = u_t K_t$. 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 average level of productivity, in t households earn from firms' value, $\upsilon_t(\tilde{z}_t)$, and profits, $j_t(\tilde{z}_t)$, from the fraction $(1-\eta_t)$ of surviving firms, while they earn the liquidation value $l\upsilon_t$ 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 costs 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:

$$FEX_t \equiv f^E + ec_t, \tag{3}$$

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 as:

$$ec_t = \Theta^e \left(\frac{N_t^E}{N_t}\right)^{\varsigma_e}, \tag{4}$$

where $\Theta^e > 0$ and $\varsigma_e > 1$.[8] 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 it serves the function of capturing the gradual response of entry over time to shocks, as observed in the data.

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

$$l\upsilon_t = (1-\tau)f^E - xc_t, \tag{5}$$

which is given by a fraction $(1-\tau)$, with $0 < \tau < 1$, of the license fee paid at entry, f^E, returned to the households by the fiscal authority once a firm exits the market, net of the exit congestion externalities, xc_t, which, as in Casares et al. (2020), are given by:

$$xc_t = \Theta^x \left(\frac{N_t^X}{N_t}\right)^{\varsigma_x}, \tag{6}$$

where $\Theta^x > 0$ and $\varsigma_x > 1$.[9]

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

$$N_t = (1-\eta_t)\left(N_{t-1} + N_{t-1}^E\right). \tag{7}$$

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:

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

Households choose capital utilization, given the adjustment cost function:

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

where γ_1 and γ_2 are positive parameters. 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):

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

Finally, households supply their homogeneous labour to an intermediate labour union which differentiates the labour services and sets wages subject to the Rotemberg (1982) adjustment costs.

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

[9] 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.

2.2. Firms

As in Rossi (2019) and in Fasani et al. (2023), 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, and they set prices subject to the Rotemberg (1982) adjustment costs.

2.2.1. Intermediate sector

Each firm in the intermediate sector produces a differentiated good under monopolistic competition and flexible prices.[10] Firms are heterogeneous in terms of their specific productivity. 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 the amount of labour hours and capital services, respectively, 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 total factor productivity (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: $\varepsilon_{A,t} = \rho_A \varepsilon_{A,t-1} + \sigma_A u_{\varepsilon_A,t}$.

This sector is characterised by endogenous firm dynamics, with the following timing. At the beginning of the period, households invest in new firms until the following entry condition is satisfied: $v_t(\widetilde{z}) = FEX_t$, that is until the average firms' value equals the entry costs. Note that the value of the firm facing the average productivity corresponds to the stock price of the economy. The latter is so given by:

$$v_t(\widetilde{z}_t) = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}((1-\eta_{t+1})(v_{t+1}(\widetilde{z}_{t+1}) + j_{t+1}(\widetilde{z}_{t+1})) + \eta_{t+1} l v_{t+1})\right], \tag{13}$$

where λ_t is the marginal utility of consumption at time t, and $j_t(\widetilde{z}_t)$ 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 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.[11] 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 $\bar{z}_t$. 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. The average output and the average firms' productivity depend on the cut-off level of productivity in the economy, $\bar{z}_t$, which is endogenously determined through the exit condition: $v_t(\bar{z}_t) = lv_t$, where the value of the firm with a productivity level equal to the marginal value $\bar{z}_t$ is:

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

Equation (14) states that the value of the marginal firm is given by its current profit, j_t, plus the continuation value, where $j_t(\bar{z}_t) = y_t(\bar{z}_t) - w_t l_{\bar{z},t} - r_t^K k_{\bar{z},t}^s$, with $w_t l_{\bar{z},t}$ the cost of labour and $r_t^K k_{\bar{z},t}^s$ the cost of capital services of the marginal firm.

The exit probability, $\eta_t = 1 - \left(\frac{z_{\min}}{\bar{z}_t}\right)^{\xi}$, is endogenously determined. As in Ghironi and Melitz (2005), the lower bound productivity level, $z_{\min}$, is low enough relative to the production costs, so that $\bar{z}_t$ 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 $\bar{z}_t$ 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

[10] 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.

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

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:

$$y_{\iota,t} = \left(\frac{p_{\iota,t}}{P_t^I} \right)^{\theta_p} Y_t^I(k), \tag{15}$$

implying the intermediate sector price index: $P_t^I(k) = \left(\int_{N_t} p_{\iota,t}^{\theta_p - 1} d\iota \right)^{\frac{1}{\theta_p - 1}}$. 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) model. The retailer's optimal price decision rule implies the following non-linear New Keynesian Phillips Curve:

$$1 = \frac{\theta_p}{\theta_p - 1} \rho_t^I - \frac{\phi_p}{\theta_p - 1} (\pi_t - 1)\pi_t + \frac{\phi_p}{2} (\pi_t - 1)^2 + \frac{\phi_p}{\theta_p - 1} E_t \left\{ \Lambda_{t,t+1} (\pi_{t+1} - 1)\pi_{t+1} \frac{Y_{t+1}}{Y_t} \right\}, \tag{16}$$

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:

$$\log\left(\frac{1 + i_t}{1 + i} \right) = \phi_R \log\left(\frac{1 + i_{t-1}}{1 + i} \right) + (1 - \phi_R)\left(\phi_\pi \log\left(\frac{\pi_t}{\pi} \right) + \phi_y \log\left(\frac{y_t}{y} \right) + \phi_{dy} \log\left(\frac{y_t}{y_{t-1}} \right) \right), \tag{17}$$

where ϕ_π, ϕ_y and ϕ_{dy} are the elasticities of the nominal interest rate with respect to the deviation of inflation from its 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:

$$T_t = f^E N_t^E - (1 - \tau) f^E N_t^X, \tag{18}$$

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 expectations shock 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:

$$\mathbb{E}_t \pi_{t+1} = [\pi_{t+1}^e] e^{\varepsilon_{\pi,t+1}}, \tag{19}$$

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:

$$\varepsilon_{\pi,t+1} = \rho_\pi \varepsilon_{\pi,t} + \sigma_\pi u_{\varepsilon,t+1}. \tag{20}$$

(19) implies that short-run inflation expectations have two components. One is the rational expectations component that is therefore endogenous to the model and affected by the central bank behavior. The second component is erratic and exogenous to the model. Inflation expectations are thus subject to deviations from rationality that cannot be controlled or affected by the policy behaviour. As argued in the Introduction, first such an assumption cannot be easily disregarded given the large evidence of non-rationality of inflation expectations in the literature on survey data. Second, the shock is an exogenous component of inflation expectations out of the direct control of the central bank. Such a component wants to capture the idea that many policy makers seem to have of inflation expectations, given the close monitoring by central banks of inflation expectations data, and the concerns about inflation expectations dynamics in many central bankers' speeches, as if expectations could move exogenously from central bank policy or communication.

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:

$$\tilde{\sigma}_{x,t} = 100ln(\frac{\sigma_{x,t}}{\sigma_x}), \qquad \text{where} \qquad \sigma^2_{x,t} = var_t(x_t) = E_t[x_{t+1} - E_t x_{t+1}]^2, \tag{21}$$

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 measures for output uncertainty, inflation uncertainty and equity return uncertainty, defined as the volatility of the expected real GDP, of the expected inflation and of the expected return on equity, respectively.

2.5. Aggregation and market clearings

The economy aggregate output is:

$$Y_t = A_t N_t^{\frac{1}{\theta_p - 1}} \widetilde{z}_t (L_t)^{1-\alpha} (K^s_t)^{\alpha}, \tag{22}$$

while the resource constraint of the economy is:

$$Y_t = C_t + I_t + a(u)K_t + N^E_t ec_t + N^X_t xc_t + PAC_t + WAC_t, \tag{23}$$

where $PAC_t = \frac{\phi_p}{2}(\pi_t - 1)^2 Y_t$ 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 IRFs of the main macroeconomic variables of our Baseline model to a positive inflation expectations shock, that is to a shock that increases inflation expectations. To understand the role played by uncertainty in affecting the dynamics of the main macro variables, we compare the IRFs obtained by approximating the model at third-order with th eone obtained approximating at first-order, where the uncertainty contribution is absent.

3.1. Calibration

The auto-regressive coefficients of the inflation expectations shock and of the technology shock are equal to 0.9 and their innovation $\sim N(0, 0.01^2)$. 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. The capital-income share α is set to 0.33, the capital depreciation rate, δ_k, 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., Bilbiie et al., 2012; Ghironi and Melitz, 2005). We set the markup in the labour market as the one 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 Casares et al. (2020). Once ec, xc, ς_e, ς_x are calibrated, the remaining constant component of the entry cost, f^E, and the parameters Θ^e and Θ^x are endogenously determined. 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. The Rotemberg parameters of price adjustment cost ϕ_p and of the of nominal wage adjustment cost ϕ_w are both equal to 40, though in the Montecarlo exercise presented in Section 3.3 we test the robustness of the results by considering higher and lower values for both parameters. The coefficients in the Taylor rule are $\phi_R = 0.75$, $\phi_\pi = 2.5$, $\phi_y = 0.01$ and $\phi_{dy} = 0.05$.[12] Finally, we back out the model-implied VXO similarly to Basu and Bundick (2017).[13]

[12] 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.

[13] 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 Eqs. 9 and 10 in the

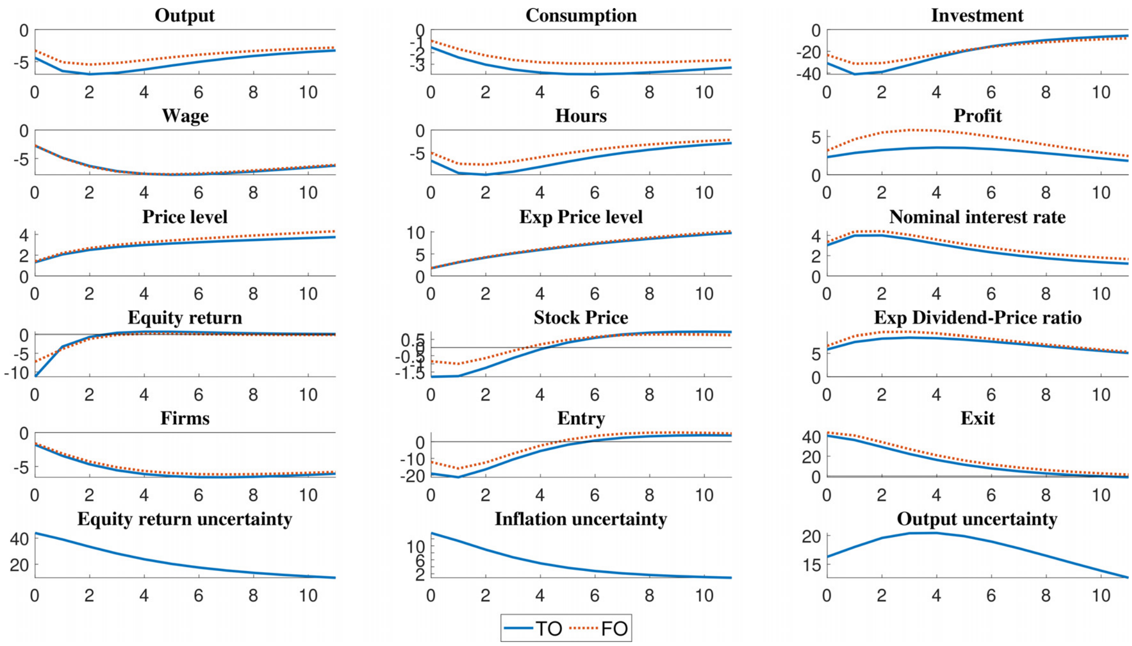

Fig. 2. Model Dynamics: responses to inflation expectations shock. First order vs third order approximation.

3.2. IRFs to inflation expectations shock

This Section examines the transmission of the shock to inflation expectations in the DSGE model, by solving 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.

Fig. 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, leading to an increase in inflation of about 1.5 percentage point and a drop in output of about 3 percentage points in the model approximated up to a first order, and even a 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. Moreover, 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 leads to a decrease in investment in new firms and thus in firm entry. In contrast, firm exit increases and the 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 both the third-order solution and 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 in 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, Fig. 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. As shown in Fig. 3, on impact the drop in output is 1.15 percentage points greater under the third-order solution (i.e., -4.41%, see Fig. 2) than under the first-order solution of the model (i.e., -3.26%, see Fig. 2), and at the peak of the recession - after two quarters from the shock - this number increases to 1.5 percentage points. Hence, the uncertainty contribution amplifies the drop in output on impact of about 1/3 of 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.

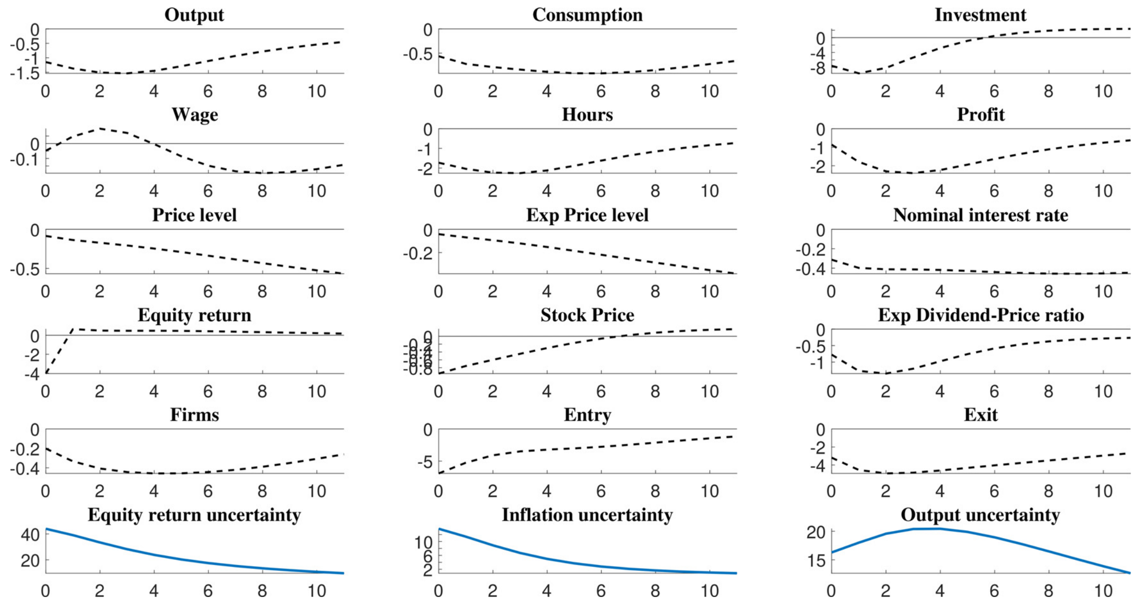

Fig. 3. Uncertainty Contributions: difference between the response derived by using the third order solution of the model minus the responses produced using only the first order solution.

impact effect under first-order.[14] Further, under the third-order solution the drop in consumption and firm entry is about 1/2 stronger than under the first-order solution, while the drop in investment and hours are about 1/3 stronger.

Overall, our findings suggest that the endogenous uncertainty channel plays a sizeable role in the transmission of the inflation expectations shock. The last row of Figs. 2 and 3 show the dynamics of three measures of endogenous uncertainty, as defined in Eq. (21): the expected volatility of output, inflation, and equity return. An increase in inflation expectations is followed by a substantial increase in the expected volatility of inflation, output, and equity returns.

3.3. Montecarlo simulations

The inflation expectations shock is thus stagflationary, that is, it reduces output and increases inflation, similarly to a standard supply shock, as a negative TFP shock. The objective of this Section is to establish a set of theory robust sign restrictions that we can use to separately disentangle these two shocks - a shock to inflation expectations from a standard TFP shock - in the data. 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. The online Appendix contains the details of this exercise.[15] The main finding is that the patterns of all the variables are qualitatively similar for the two shocks, except for the response of profits, the expected dividend-price ratio and output uncertainty. 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 expectations shock from a standard supply shock.

4. 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-quarter ahead forecast of GDP deflator, GDP deflator, equity return, dividend-to-price ratio, VXO, 1-quarter ahead forecast dispersion of real GDP, 1-quarter 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

[14] We compute the relative contributions as difference between the responses of the third and first-order solutions (see Fig. 3) divided by the response of the first order solution (see Fig. 2).

[15] The online Appendix reports in a Table the chosen bounds for the uniform distributions of parameters considered in this Montecarlo exercise. Moreover, it contains the two Figures displaying the distribution of the IRFs in response to an inflation expectations shock and to a supply shock respectively, resulting from the simulation exercise.

Table 1
Sign Restrictions. SPF → Survey from Professional Forecasters, GDPD → GDP Deflator, RGDP → real GDP.

	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	+	+

research (FRED-QD database). The measure of equity return is the value-weighted total stock market return (vwretd) taken from CRSP. Data on the dividend-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. Table 1 summarises the sign restrictions derived from the Montecarlo simulations of 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 expectations shock.

Furthermore, following Antolín-Díaz and Rubio-Ramírez (2018) we impose a narrative sign restriction to better identify the inflation expectations shock. Paul Volcker was nominated to fight inflation and this was publicly known during the nomination process.[16] We use this information as a narrative restriction to identify the impact of inflation expectations shock. 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.

Fig. 4 shows the IRFs to an inflation expectations 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 online Appendix reports the IRFs to a supply shock and the relative contribution of the two shocks in explaining the volatility of the variables at different horizons. It also reports and comments on the series of the median of the identified inflation expectations shocks.

The same Appendix also reports several robustness checks. First, it shows that our results are robust to alternative VAR estimations which use 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.

The identification strategy in the VAR is based on sign restrictions derived from the Montecarlo simulation of the DSGE model, once it is solved at the third order. Different from the VAR, the model is nonlinear, so there could be an inconsistency between the two specifications. However, the VAR incorporates information from both macroeconomic variables and their expected volatility. This allows endogenous variables and measures of endogenous uncertainty to interact. Feedback from the volatility to endogenous variables in the DSGE model is therefore granted for the VAR. Hence, this mitigates concerns about the identification of the shock in the VAR, despite the linear specification. Finally, the online 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 online 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.

[16] 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.

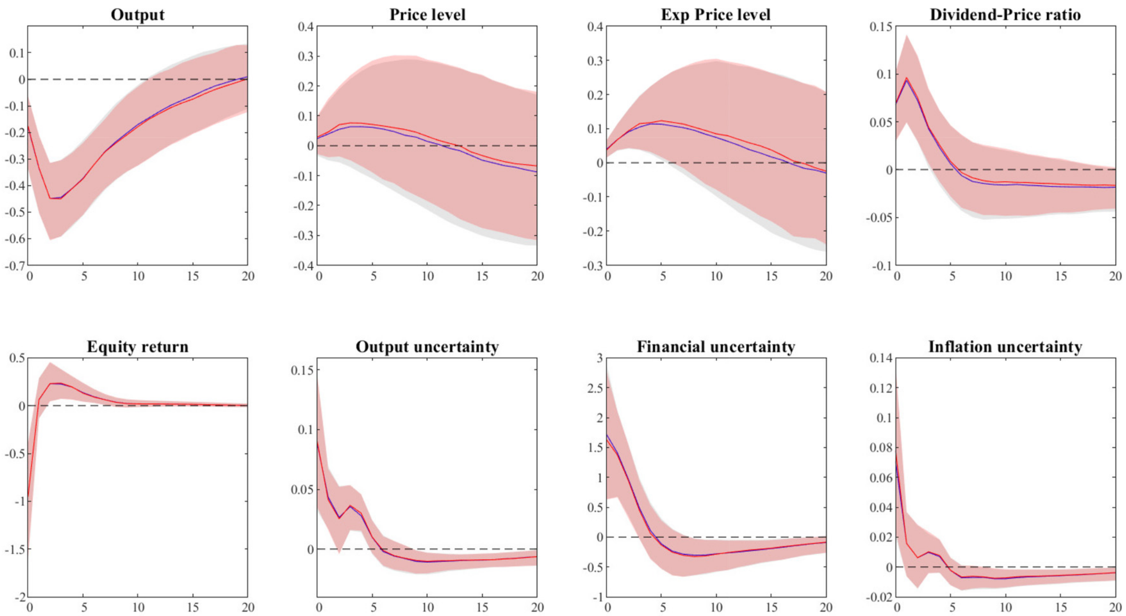

Fig. 4. VAR impulse response functions to an **inflation expectations shock** (68% percentile): in grey the estimated IRFs obtained using only sign restrictions, in red the estimated IRFs obtained using sign restrictions and the narrative. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Parameter Estimates through IRFs matching. Labels: *TO* = Third Order solution of the Baseline model; *FO* = First Order solution; *TO-no-firms* = Third Order solution of model with no firm dynamics; *Shock (-)* = Negative shock.

Estimated Parameters		*TO*	*FO*	*TO-no-firms*	*Shock (-)*
"Deep" parameters					
γ_p	Rotemberg Adjust. Cost - Price	18.9	19.1	32.32	34.70
γ_w	Rotemberg Adjust. Cost - Wage	112.8	42.6	95.42	92.59
γ_i	Investments Adjustment Cost	5.78	7.28	2.11	6.11
Shock parameters					
σ_π	Std. of Inflation Expect. shock	0.0003	0.0006	0.0006	0.0006
ρ_π	Persist. Inflation Expect. shock	0.7680	0.5448	0.4988	0
Taylor rule					
ϕ_π	Coefficient Inflation	3.96	4.55	1.98	2.83
ϕ_y	Coefficient Output	0.0450	0.0189	0.0055	0.0233
ϕ_{dy}	Coefficient Output growth	0	0.0025	0.0943	0
ϕ_R	Interest rate smoothing	0.3890	0.7776	0.5551	0.7100
Value Function		44.94	61.45	62.24	70.61

5. Model estimation

In this Section, we estimate a set of the model parameters of our Baseline model conditional on an inflation expectations shock, using a limited information impulse response matching techniques in the spirit of Christiano et al. (2005), Basu and Bundick (2017), Mumtaz and Theodoridis (2020).

5.1. Third-order versus first-order

To show the important 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 model approximations, while the remaining parameters are estimated in each models using a limited information impulse response matching techniques to match the SVAR-IRFs of real GDP, consumer price index, expected price index and the return on equity to the identified inflation expectations shock.

Table 2 shows the list of the estimated parameters in the first two columns, and their values obtained using the SVAR-IRFs and the model-IRFs for both the third order and the first order solution of the same Baseline model in the third and in the fourth column (labelled as *TO* and *FO*, respectively, in the Table). 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

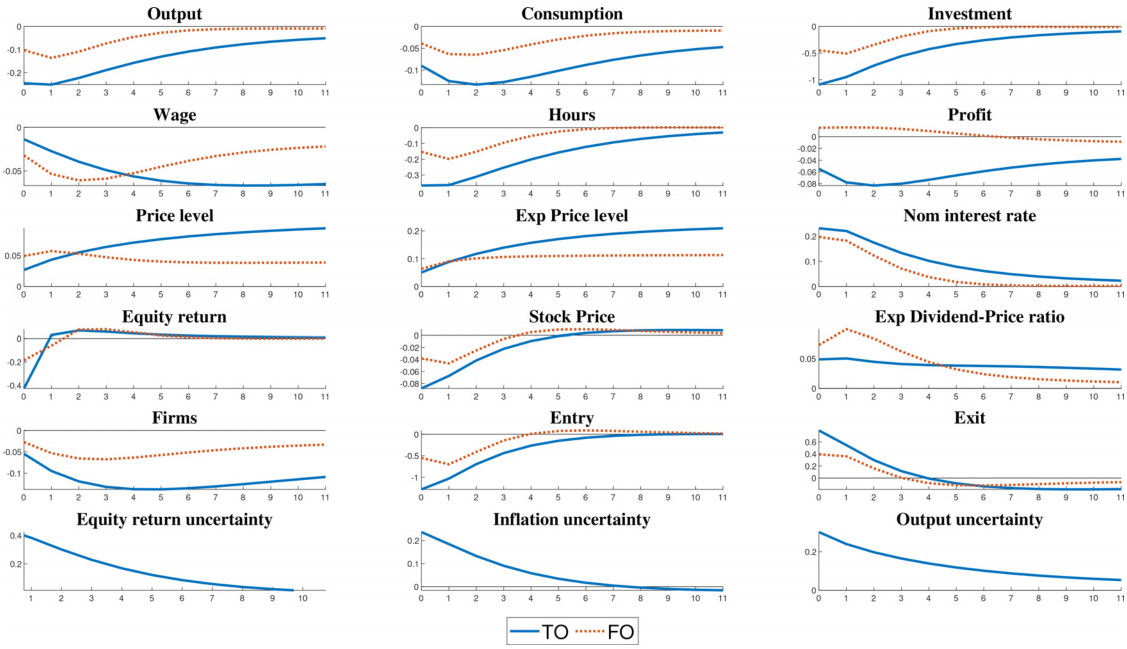

Fig. 5. Dynamic responses to an inflation expectations shock using estimated parameters: FO vs TO model.

approximation is smaller than the one 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.[17] 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, Fig. 5 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.

5.2. 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 fifth column in Table 2 shows the results of the estimation. With respect to our Baseline model, the model without firms dynamics exhibits: (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 Fig. 6. 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 is consistent with the recent findings by Bilbiie and Melitz (2020). These authors show that endogenous entry-exit radically changes the effects 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.

[17] This is also clear by comparing the model-IRFs and the VAR-IRFs in the two cases. The online Appendix contains a Figure showing that the third order approximation of the model generates IRFs that are closer to those obtained in the VAR.

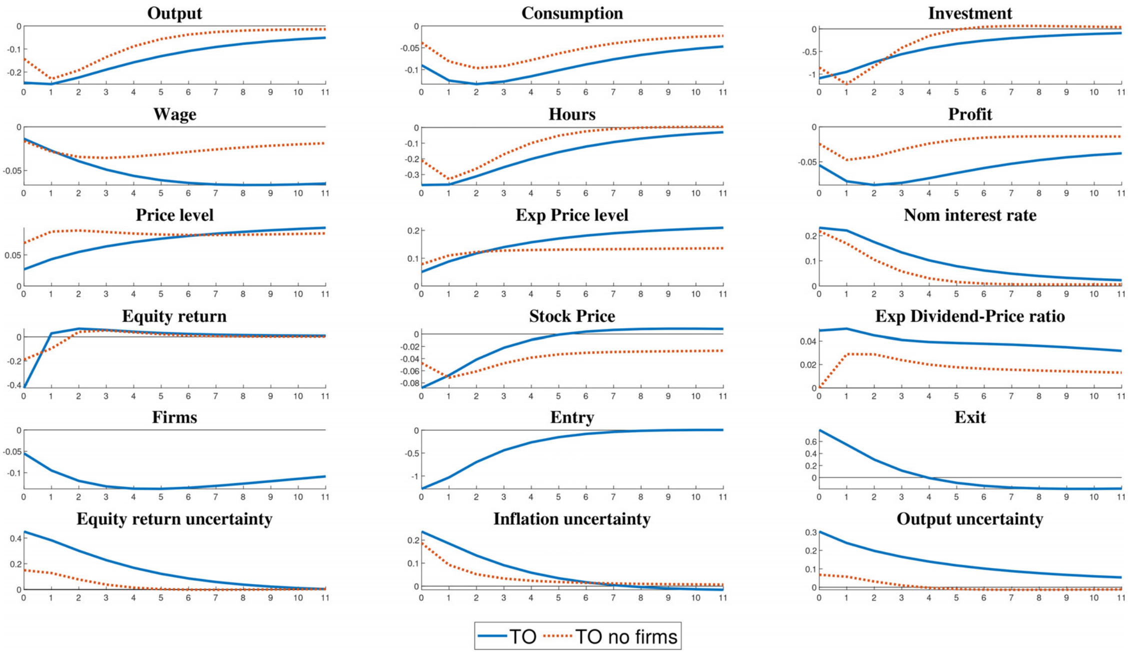

Fig. 6. IRFs to inflation an expectations shock using estimated parameters TO vs TO no firms model.

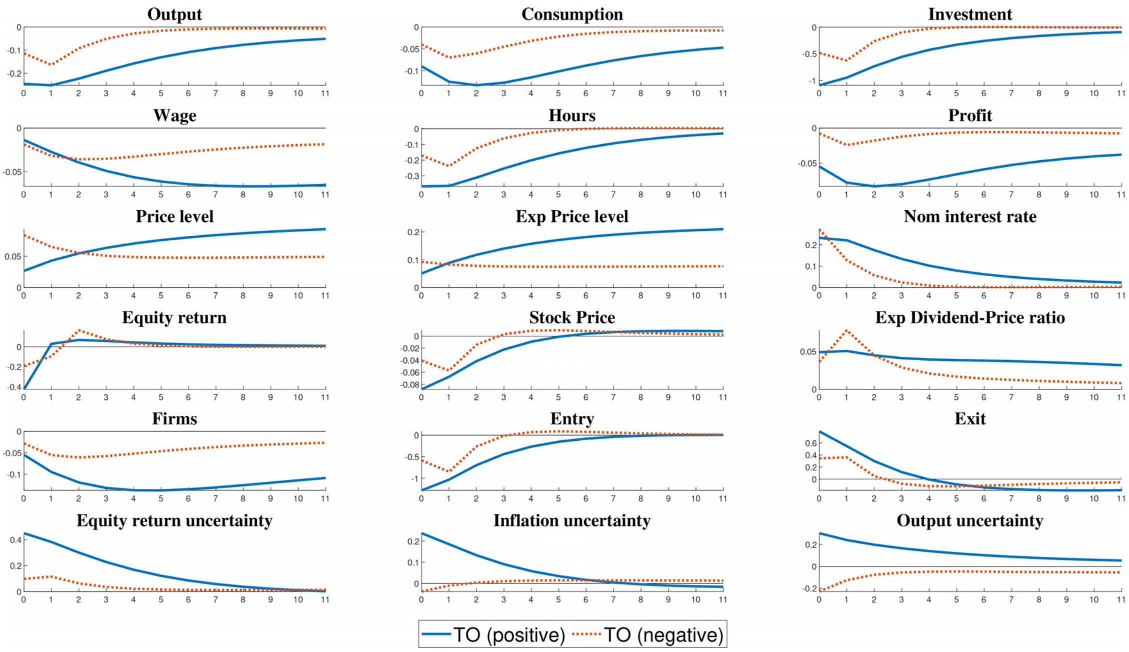

Fig. 7. Re-estimating the model: positive (inflationary) versus negative (deflationary) inflation expectations shock (negative IRFs multiplied by -1).

6. Asymmetries

This Section investigates, the possible asymmetric effect of shocks to inflation expectations. More precisely, we ask whether the effects of shocks that increase inflation expectations are symmetric to shocks that reduce inflation expectations.

To this scope the estimation done in Section 5 is repeated 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. The sixth column in Table 2 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.

Fig. 7 shows the implied IRFs to a one standard deviation increase in inflation expectations and to a one standard deviation exogenous decrease in inflation expectations, using the parameters estimated in Table 2 (column 1 for the positive shock and column 4 for the negative one). For a easier comparison between the two types of IRFs, the IRFs corresponding to a negative inflation expectations shock are multiplied by -1. The positive inflation expectations shock has stronger effects than the negative one on all the real variables: output, consumption, investment, hours and profits. Moreover, also firms dynamics is more affected by a positive shocks in terms both of entry and exit and hence number of firms. Finally, also the uncertainty measures reacts more promptly, and actually the responses of inflation and output uncertainty have the opposite sign. All in all, Fig. 7 shows that the IRFs to a positive and to a negative inflation expectations shock are quite different, illustrating the asymmetry in the effects of the inflation expectations shock. The online Appendix performs a local projection analysis, using the structural shock estimated in the linear VAR model in Section 4. First, the analysis not only confirms that the shock is stagflationary, but also that, in line with our DSGE model, the expectations shock has negative effect on variables not present in the VAR as consumption, investment and hours. Therefore, even expanding the empirical analysis to other variables, the findings confirm the detrimental effect of increased inflation expectations for the economic activity. Second, the local projections analysis confirms the asymmetric effects of an inflation expectations shock, as the negative effects of inflation expectations shock for output, dividend-to-price ratio, and output uncertainty are larger - in absolute value - for a shock that increases inflation expectations rather than decreases them.

7. 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. 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. Last, but not least, the model economy shows the existence of asymmetric effect in the transmission of inflation expectations shock. Shocks that increase inflation expectations imply a stronger effect on the main real variables than shocks that reduce inflation expectations.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jmoneco.2023.04.002

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