Uncertainty shocks: it's a matter of habit

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Abstract

This paper provides empirical and theoretical evidence that uncertainty shocks have strong asymmetric effects on economic activity. Specifically, in the empirical analysis I find that uncertainty shocks dampen investment and consumption twice as much during recessions than in "normal" times. In the theoretical analysis I employ a sticky-prices general equilibrium model featuring external habit formation to show that the asymmetric effects of uncertainty shocks can be explained by countercyclical fluctuations in precautionary savings.

Keywords: Uncertainty Shocks, STVAR, External habits, Precautionary savings.
JEL classification: E21, E32.

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1 Introduction

> *"The most recent GDP data confirm that the recovery in the euro area remains uniformly weak, with subdued wage growth even in non-stressed countries suggesting lackluster demand. In these circumstances, it seems likely that uncertainty over the strength of the recovery is weighing on business investment and slowing the rate at which workers are being rehired."*
>
> Speech by Mario Draghi, President of the ECB, Annual central bank symposium in Jackson Hole, 22 August 2014

The 2008 global financial crisis has led to a sharp increase in fiscal deficits that has dragged Europe into a debt crisis. We have therefore witnessed to a surge in the perceived risk over the sustainability of the debts of several European member states. This crisis has also casted doubts on the stability of the banking system and on the sustainability of the monetary union itself. Forseeing when the recession is going to end appears to be particularly difficult in this environment. As the recent quotation of Mario Draghi shows, high uncertainty on the economic outlook is seen by economists and policy makers as a major factor holding back the European economy to recover from the cyclical downturn. In times of high uncertainty firms postpone investment decisions, reduce hirings and consumers increase their savings for precautionary reasons.

Explaining how uncertainty affects business cycle fluctuations is a relevant question from both theoretical and policy perspectives. A growing literature studies the effects of uncertainty shocks on economic activity. This literature has been initiated by the seminal contribution by Bloom (2009). The analysis of uncertainty shocks is a challenging task both from an empirical and a theoretical point of view. The latent nature of uncertainty has led the empirical literature to investigate its effects on the economy using various proxies, such as survey data (for instance Leduc and Liu (2012) and Bachmann and Sims

(2012)) and stock market's implied and realized volatility (Bloom (2009) and Caggiano et al. (2013)). This literature has found that uncertainty shocks have significant contractionary effects on the economy and act like negative demand shocks, by increasing unemployment and reducing inflation (Leduc and Liu (2012)).

The ways uncertainty can affect economic activity have been widely analyzed in the theoretical literature. In particular, four key channels have been identified: the real options channel, that can lead firms to increase or decrease their investment (Bernanke (1983)); the Hartman-Abel effect that leads firms to expand in response to positive uncertainty shocks and contract after negative shocks (Hartman (1976) and Abel (1983)); the precautionary savings channel that makes agents reduce their consumption when uncertainty increases (Leland (1968)); risk-premium effects that increase the cost of financing when uncertainty rises. These channels have potentially contrasting effects and in a general equilibrium (GE) context they may offset each other. For this reason the macroeconomic literature has provided mixed evidence on the importance of uncertainty shocks in determining business cycle fluctuations in a GE framework [1]. Basu and Bundick (2011) show that uncertainty shocks are able to generate business cycle fluctuations only in sticky-prices (New-Keynesian) frameworks. In flexible-prices models instead, the precautionary savings channel leads consumption to fall and labor supply to increase. The rise in labour supply increases total output, which implies an increase in investment, given the fall in consumption. Cesa-Bianchi and Fernandez-Corugedo (2013) explain that while idiosyncratic uncertainty shocks affect economic activity mainly through the cost of external finance and entrepreneurial capital demand, aggregate uncertainty shocks operates mainly via the precautionary savings channel.

[1] Relevant contributions have been provided by Bachmann and Bayer (2013), Born and Pfeifer (2013), Fernandez-Villaverde et al. (2011b), Gilchrist and Zakrajsek (2012), Christiano et al. (2010)

As the words by Mario Draghi show, uncertainty is considered to have particularly severe effects when the economy is in a recessionary phase. The present paper extends the literature by casting some light on the asymmetric effects of aggregate uncertainty on economic activity. I estimate a Smooth Transition Vector Autoregressive (STVAR) model for the United States (US) that allows to study the macroeconomic effects of uncertainty shocks under different regimes. I find that in times of recession uncertainty shocks have stronger dampening effects on consumption and investment than in "normal" times. Specifically, the impulse response analysis shows that investment and consumption fall twice as much during recessions than a linear VAR would imply[2]. Secondly, I employ a New Keynesian model with heterogeneous agents, similarly as in Iacoviello (2005), in order to explain the empirical findings. In particular I focus on the role of countercyclical fluctuations in precautionary savings and find that these crucially amplify the macroeconomic effects of uncertainty shocks and represent an important factor that can explain the asymmetric effects found in the data. The countercyclical swings in precautionary savings are introduced by including persistent external habits[3]. The inclusion of persistent external habits strongly amplifies the dampening effects of uncertainty shocks on consumption and investment. The reason is that once we account for external habits, uncertainty shocks increase precautionary savings not only by directly raising macroeconomic uncertainty, but also via an indirect channel that I define as "feedback effect". By solely increasing macroeconomic uncertainty, we have a fall in consumption, investment and hours worked. The fall in economic activity raises precautionary savings even further, which worsens the economic downturn (feedback effect). The impulse response analysis delivers two main results: the feedback effect is nonlinear and is quantitatively more relevant than the pure increase in macroeconomic uncertainty; countercyclical fluctuations in precautionary

[2] A related work is that by Caggiano et al. (2013), who focus on the asymmetric relationship between uncertainty shocks and unemployment in the US

[3] For more details on the relationship between countercyclical fluctuations in precautionary savings and persistent external habits see Cochrane and Campbell (1999) and De Paoli and Zabczyk (2013)

savings can explain the asymmetric effects of uncertainty shocks on economic activity, both at a qualitative and a quantitative level.

The rest of the paper is organized as follows: section 2 presents empirical evidence on the asymmetric macroeconomic effects of uncertainty shocks; section 3 provides a theoretical explanation with a Dynamic Stochastic General Equilibrium (DSGE) model; section 4 concludes the paper with some final remarks.

2 Empirical evidence: a STVAR analysis

2.1 The methodology

In this section I present empirical evidence on the asymmetric effects of uncertainty shocks on economic activity. In order to do so, I estimate a logistic STVAR, following the methodology employed by Auerbach and Gorodnichenko (2013), Bachmann and Sims (2012) and Caggiano et al. (2013). The advantage of this methodology, in contrast with linear VARs, is that the response of the variables to the uncertainty shock will depend on the state of the economy. The specification of the STVAR model is given by:

$$Y_t = (1 - F(v_{t-1}))\,\Gamma_{EXP}(L)\,Y_{t-1} + F(v_{t-1})\,\Gamma_{REC}(L)\,Y_{t-1} + \eta_t \tag{1}$$

$$\eta_t \sim \mathcal{N}(0, \Sigma_t) \tag{2}$$

$$\Sigma_t = \Sigma_{EXP}(1 - F(v_{t-1})) + \Sigma_{REC} F(v_{t-1}) \tag{3}$$

$$F(v_t) = \frac{\exp(-\gamma v_t)}{1 + \exp(-\gamma v_t)}, \quad \gamma > 0 \tag{4}$$

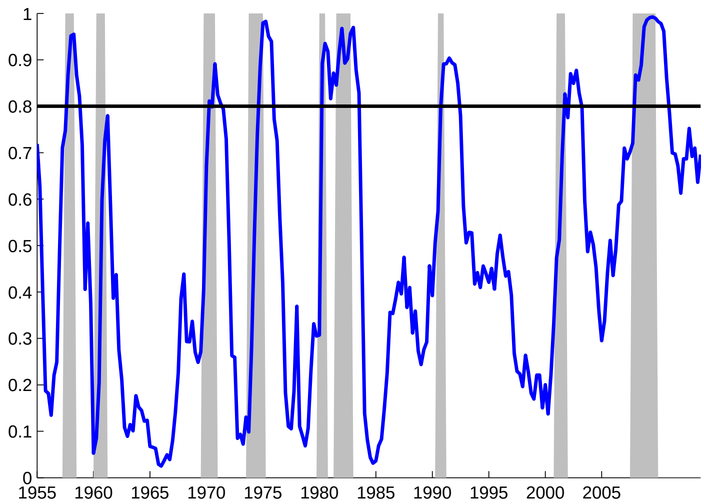
$$\mathbb{E}[v_t] = 0 \text{ and } \operatorname{var}(v_t) = 1 \tag{5}$$

where $Y_t = [\text{Uncertainty}_t,\, C_t,\, I_t,\, R_t]$, i.e. the vector of endogenous variables, given by the uncertainty index, consumption, investment, and nominal interest rate. $F(\cdot)$ denotes the logistic function, while v_t is the transition variable. The matrices $\Gamma_{EXP}(L)$ and $\Gamma_{REC}(L)$ represent the coefficients that capture the dynamics of the system during expansionary and recessionary phases of the business cycle. The vector η_t is the vector of errors of the reduced form model. These errors are assumed to be jointly normal with zero mean and variance-covariance matrix Σ_t. Moreover Σ_t is time varying and state contingent. Σ_{EXP} is the variance-covariance matrix of the reduced form errors during expansions, while Σ_{REC} is the variance-covariance matrix of the reduced form errors during recessions. The matrices Σ_{EXP} and Σ_{REC} capture the contemporaneous effects of the shocks.

Similarly as in Auerbach and Gorodnichenko (2013), the transition variable v is defined as a seven-quarter moving average of the output growth rate. The logistic function $F(v_t)$ is bounded between 0 and 1 and can be interpreted as the probability of being in a recession, given observations on v_t. If $F(v_t) \approx 1$, v_t must be very negative , while if $F(v_t) \approx 0$, v_t is very positive. A recession is defined as a period in which $F(v_t) > 0.8$. The parameter γ is fixed to facilitate the estimation of the model's parameters, given the high nonlinearity of the system. I set γ to 1.5 to match the observed frequency of recessions in the United States since 1946 according to the NBER business cycles dates (approximately 21%). The parameter γ is hence chosen such that $\Pr(F(v_t) > 0.8) \approx 0.21$. When γ is equal to 0 the STVAR reduces to a linear VAR. Figure 1 compares the cyclical indicator $F(v_t)$ with the recessions as dated by the NBER (grey shaded areas).

The highly nonlinear model described by equations (1)–(5) is estimated by maximum likelihood using Monte Carlo Markov Chain methods (Chernozhukov and Hong (2003)). Under standard conditions, this approach finds a global optimum in terms of fit. The parameter estimates and their standard

Figure 1: *Probability of being in a recessionary state*



Notes: The blue line is the probability of being in a recession, $F(v_t)$; the grey shaded areas are the recessionary phases as dated by the NBER; black line is threshold value I used to define a recession.

errors are computed directly from the generated chains. The transition variable v_t is treated as an exogenous variable and is not included in the vector Y_t. The estimated STVAR features 1 lag following the Bayesian Information Criterion (BIC).

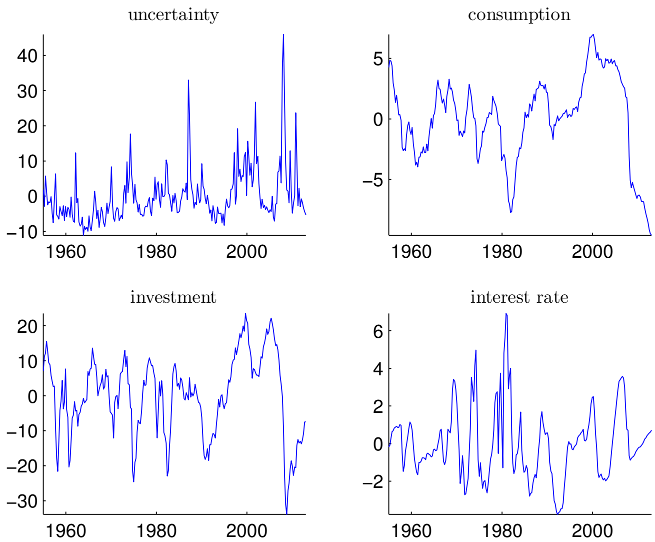
2.2 Data and test for linearity

The model is estimated with quarterly data for the United States. The time span considered is 1955Q1-2013Q4. I collect the data on real GDP, consumption, investment, federal funds rate and uncertainty from the FRED database of the Federal Reserve of St.Louis. I take the logarithm of the series for GDP, consumption and investment. As in Weise (1999), I take into account potential structural breaks. This is necessary because nonlinearity might arise solely because of time-dependent structural breaks. In order to avoid this risk, I filter the series for consumption, investment and the interest rate by regressing them on a constant, dummy variables for the post-1972 and post-1979 periods, a time trend and the time trend interacted with the dummy variables. Figure (2) displays the filtered series and the demeaned uncertainty index that have been used for the estimation of the STVAR model.

The measure of uncertainty has been broadly discussed in the literature (see for instance Bloom (2009) and Baker et al. (2012)). Economic uncertainty refers to an environment in which little or nothing is known about the future state of the economy. Economic uncertainty can stem from various sources such as economic and financial policies, dispersion in future growth prospects, productivity movements, wars, terrorist attacks, and natural disasters (Bloom (2009)). The latent nature of uncertainty makes this variable difficult to quantify. In this paper I use the VIX index as a proxy for aggregate macroeconomic uncertainty . The VIX is a measure of the implied volatility of the S&P 500 index option prices. It represents a measure of the market's expectation of stock market volatility over the next 30 days. This measure has been widely used in the literature to identify uncertainty shocks (e.g. Basu and Bundick (2011)). However, the VIX index is available only since 1986, therefore prior to 1986 I approximate it as in Bloom (2009). Specifically, I compute monthly standard deviations of the S&P 500 returns and rescale the series such that it has the same mean and variance as the VIX index. Figure 2 displays the data employed for the estimation of the STVAR model, except for the transition variable v that has been described in the previous section.

Before estimating the STVAR, I perform a linearity test to determine whether nonlinearity is in fact relevant in our case. The testing strategy employed consists of a three-steps procedure as in Weise (1999) and Granger and Terasvirta (1993). Testing for linearity consists of testing the hypothesis $H_0 : \gamma = 0$ against $H_0 : \gamma > 0$. Consider a K-variable VAR with

Figure 2: *Variables used for the estimation*



NOTES: The variables displayed are the endogenous variables used for the estimation of the STVAR model. The series of consumption, investment and federal funds rate are filtered. The uncertainty measure is demeaned.

L lags and let S_t be the vector of lags of all endogenous variables, i.e. $S_t = [y_{1,t-1},\, y_{1,t-2}, \dots y_{1,t-L},\, y_{2,t-1}, \dots y_{K,t-1}, \dots y_{K,t-L}]$, where $y_{k,t}$ is the k-th endogenous variable of the VAR at time t. The first step consists of collecting the residuals $\hat{e}^R_{k,t}$ from the restricted regression:

$$y_{k,t} = \beta_{k,0} + \sum_{j=1}^{LK} \beta_{k,j} W_{j,t} + e^R_{k,t}; \tag{6}$$

The second step is to collect the residuals $\hat{e}^{UR}_{k,t}$ from the unrestricted regression:

$$y_{k,t} = \alpha_{k,0} + \sum_{j=1}^{LK} \alpha_{k,j} W_{j,t} + \sum_{j=1}^{LK} \delta_{k,j} v_t W_{j,t} + e^{UR}_{k,t}; \tag{7}$$

where v_t is again the transition variable. In order to test for linearity simultaneously in all of the equations of the VAR, I calculate the likelihood-ratio

(LR) statistic $LR = T(\log|\Omega_0| - \log|\Omega_1|)$, where Ω_0 and Ω_1 are the estimated variance-covariance matrices of the residuals from the restricted and unrestricted regressions. The LR statistic is χ^2 distributed with $L \cdot K^2$ degrees of freedom. In my empirical application, I reject the null hypothesis of linearity. In particular, the $p-$value associated with the LR statistic is equal to $3.8911 \cdot 10^{-11}$.

2.3 Impulse Response Analysis

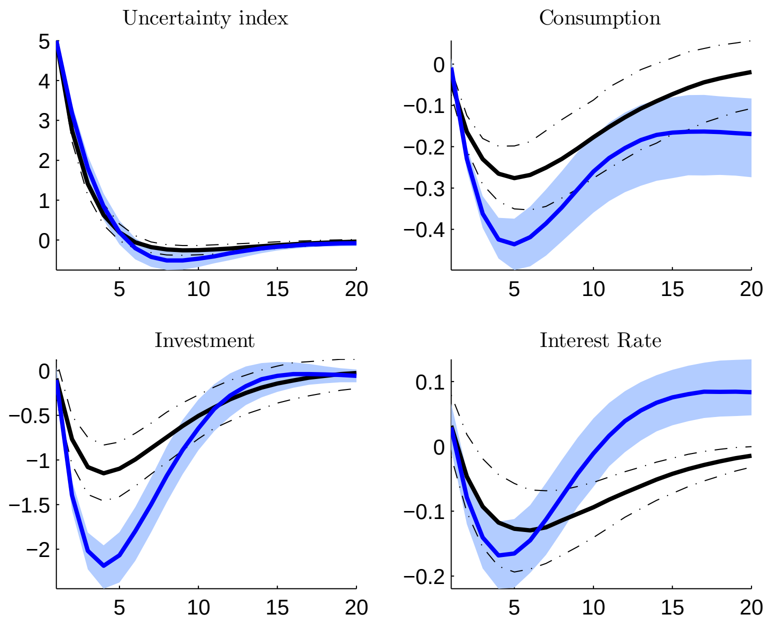
In this subsection I discuss the impulse responses (IRFs) obtained from the STVAR model for the recessionary regime and compare them to the IRFs implied by a simple linear VAR.

As in Auerbach and Gorodnichenko (2013), the impulse responses to an uncertainty shock are calculated for a given regime, disregarding possible transitions from one regime to another. This strategy considerably simplifies the computation of the impulse responses that will not depend on the history, since the model is linear in a given regime (Koop et al. (1996)). For both models (i.e. nonlinear and linear VAR), the identification of the structural shocks is obtained with a Choleski scheme. A lower triangular Choleski decomposition of the variance matrix of the reduced form residuals implies that each variable in the system is not contemporaneously affected by the shocks to the variables that are placed lower in the ordering. The ordering of the variables that I consider is analogous to that in other papers in the literature, such as Bloom (2009). The top variable is the uncertainty index, followed by consumption, investment and the interest rate.

The IRFs to a one standard deviation uncertainty shock for the linear and nonlinear models are depicted in Figure 3. The conclusion we can draw from the IRF analysis is threefold. First, the IRFs show that the uncertainty shock has a significant contractionary effect on economic activity. Second, the fall in consumption, investment and the interest rate shows that the effect of an uncertainty shock on the economy is analogous to that of a negative demand shock, similarly as in Leduc and Liu (2012). Moreover, as explained by Basu and Bundick (2011), the negative effect on both consumption and investment suggests that uncertainty shocks should be analyzed within a sticky-prices GE model. In flexible-price models in fact, uncertainty shocks do not generate business cycle fluctuations. Specifically, when prices are flexible, investment might rise after an uncertainty shock. Third, there are significant differences between the impulse responses of the linear VAR (black solid lines) and those of the STVAR (blue solid lines). During recessions, a one standard deviation uncertainty shock causes consumption to fall by 0.5 percent, and roughly by 0.25 percent with a linear VAR. Investment falls by 2.5 percent after four quarters in a recessionary regime, while with a linear VAR the fall in investment is only half as strong. The short-term interest rate falls in a less pronounced way and the IRFs of the linear VAR and of the STVAR are not significantly different.

One potential driver of the asymmetric effects depicted in figure 3 is represented by the countercyclical fluctuations in precautionary savings. The empirical literature has found that precautionary savings are time-varying and countercyclical due to time-varying risk aversion and time-varying discount factors (see for instance Guiso et al. (2013)). Therefore in periods of recessions individuals tend to be more risk averse and to save more for precautionary reasons, thereby amplifying the effect of an uncertainty shock. In section 3 I employ a DSGE model to evaluate how the effects of uncertainty shocks change qualitatively and quantitatively when accounting for countercyclical fluctuations in precautionary savings.

Figure 3: *Nonlinear and linear IRFs after an uncertainty shock*



Notes: The black solid line is the IRF of the endogenous variable to a one-standard-deviation uncertainty shock with a linear VAR. The blue solid line is the IRF of the endogenous variable in a recessionary regime. The black dotted line and the shaded area represent 68 percent error bands.

3 Theoretical explanation: a DSGE approach

3.1 The Model

I consider a DSGE model with heterogeneous agents, namely households and entrepreneurs, similar to Iacoviello (2005). Households are assumed to be more patient than entrepreneurs such that in equilibrium households will be net lenders and entrepreneurs will be net borrowers. Entrepreneurs are able to borrow up to a fraction of their collateral's value. Hence, entrepreneurs face a borrowing constraints á la Kiyotaki and Moore (1997). In this model I assume that the collateral is represented by physical capital[4]. Household own the final-good firms (retailers), while entrepreneurs own the intermediate-

[4] differently from Iacoviello (2005) who uses housing as collateral

good firms and the capital-producing firms. The latter are necessary in order to obtain the price of capital, that is necessary to determine the value of the entrepreneurs' collaterals.

The model is a New-Keynesian model. The price-stickiness is introduced with price-setting frictions at the retail sector level as in Bernanke et al. (1999). This friction is necessary in order to obtain a comovement of output, consumption, investment and hours worked (Basu and Bundick (2011)). As I am interested in investigating whether countercyclical fluctuations in precautionary savings can explain the asymmetric macroeconomic effects of uncertainty shocks, I opted for this particular setup in which the role of savers (households) and investors (entrepreneurs) is separated.

3.1.1 Households

Each household i chooses consumption $c_t^h(i)$, labor $n_t(i)$ and loans $s_t(i)$ in order to maximize its expected lifetime utility :

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \left[log(c_t^h(i) - \tau X_t^h) - \frac{n_t(i)^{1+\phi}}{1+\phi} \right] \tag{8}$$

where β_h is the household's discount factor and ϕ is the inverse of the Frisch labor supply elasticity. I assume that habits are external, i.e. individuals treat them as exogenous. The external habits X_t^h evolve according to the following law of motion:

$$X_t^h = \rho_X X_{t-1}^h + (1-\rho_X) c_{t-1}^h, \tag{9}$$

where c_{t-1}^h is aggregate households' consumption at time $t-1$. Each household faces the following budget constraint:

$$c_t^h(i) + s_t(i) = w_t n_t(i) + \frac{1+r_{t-1}}{(1+\pi_t)} s_{t-1}(i) + J_t^R(i), \tag{10}$$

where w_t is the real wage per unit of labour, $(1 + r_{t-1})/(1 + \pi_t)$ represents the interest accrued from last period's loans, divided by inflation. Finally, J_t^R denotes the profits of the monopolistically competitive retail sector.

3.1.2 Entrepreneurs

Entrepreneurs are less patient than households, i.e. they discount the future more heavily than households, $\beta_h > \beta_e$. This implies that in equilibrium households will be net borrowers and entrepreneurs will be net lenders. Each entrepreneur j maximizes her lifetime utility by choosing consumption $c_t^e(j)$, borrowing $b_t(j)$, capital $k_t(j)$ and labor input $n_t(j)$

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_e^t \Big[\log(c_t^e(j)) \Big], \tag{11}$$

subject to:

$$c_t^e(j) + w_t n_t(j) + \frac{1 + r_{t-1}}{(1 + \pi_t)} b_{t-1}(j) + q_t^k k_t(j) = \frac{y_t^e(j)}{x_t} + b_t(j) + (1 - \delta) q_t^k k_{t-1}(j), \tag{12}$$

where q_t^k is the real price of capital and $1/x_t = P_t^W / P_t$ is the relative price of the intermediate good. Entrepreneurs own competitive firms that produce a homogeneous intermediate good, featuring a constant returns to scale Cobb-Douglas production function:

$$y_t^e(j) = z_t [k_{t-1}(j)]^{\alpha} n_t(j)^{1-\alpha}, \tag{13}$$

where z_t represents total factor productivity (TFP) and α is the output elasticity of capital. Moreover, entrepreneurs face the following borrowing constraint á la Kiyotaki and Moore (1997):

$$(1 + r_t) b_t(j) \leq m \mathbb{E}_t [q_{t+1}^k (1 + \pi_{t+1})(1 - \delta) k_t(j)], \tag{14}$$

where the left-hand side is the amount of debt the entrepreneur has to pay back and the right-hand side is the value of the collateral, i.e. the value of the physical capital. The parameter m is the loan-to-value (LTV) ratio. Given that $\beta_h > \beta_e$, we have that in equilibrium the borrowing constraint (14) is binding.

3.1.3 Capital producers

Perfectly competitive firms produce new capital by mixing raw output, i_t, purchased from the retail firms at price P_t, and last period's undepreciated physical capital $(1-\delta)k_{t-1}$, purchased from the entrepreneurs at price Q_t^k. In order to transform final goods into capital, these firms face quadratic adjustment costs. These new capital goods are then sold back to the entrepreneurs at the same price Q_t^k. Since the capital-producing technology assumes constant returns to scale, these firms earn zero profits in equilibrium. Capital producers choose k_t and i_t in order maximize then their expected discounted profits:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^e \left(q_t^k \Delta k_t - i_t \right), \tag{15}$$

subject to the following law of motion of capital:

$$k_t = k_{t-1} + \left[1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right] i_t, \tag{16}$$

where Δk_t is the first difference of the capital process, $k_t - k_{t-1}$. Recall that entrepreneurs own the capital producing firms. Therefore these firms discount profits taking as given the entrepreneurs' stochastic discount factor, $\Lambda_{0,t}^e \equiv \frac{\beta_e c_0^e}{c_t^e}$. The real price of capital q_t^k is defined as $\frac{Q_t^k}{P_t}$. The coefficient $k_i > 0$ is the investment adjustment cost parameter.

3.1.4 Retailers

Similarly as in Bernanke (1983), final good producers or retailers face nominal adjustment costs when changing their prices and act in a monopolistically competitive market. There is a continuum of final goods produces of mass

1, owned by the households, that purchase the intermediate-good from the entrepreneurs in a competitive market at price P_t^W, then slightly differentiate it at no additional cost. Each retailer, indexed by ν, sells a quantity of output $y_t(\nu)$ at price $P_t(\nu)$. The aggregate output is then defined as:

$$y_t = \left[\int_0^1 y_t(\nu)^{(\epsilon^y - 1)/\epsilon^y} \mathrm{d}\nu \right]^{\epsilon^y/(\epsilon^y - 1)}, \tag{17}$$

with the associated price index:

$$P_t = \left[\int_0^1 P_t(\nu)^{(1-\epsilon^y)} \mathrm{d}\nu \right]^{1/(1-\epsilon^y)}. \tag{18}$$

In (17) and (18), ϵ^y represents the elasticity of substitution between final goods. Given (17), each retailer faces an individual demand equal to:

$$y_t(\nu) = \left(\frac{P_t(\nu)}{P_t} \right)^{-\epsilon^y} y_t. \tag{19}$$

Each firm ν maximizes the expected discounted value of profits with respect to its price $P_t(\nu)$, taking the demand for consumption goods (19) and the intermediate goods price P_t^W as given:

$$\underset{\{P_t(\nu)\}}{max}\, \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^h \left[\left(P_t(\nu) - P_t^W \right) y_t(\nu) - \frac{k_P}{2} \left(\frac{P_t(\nu)}{P_{t-1}(\nu)} - (1+\pi) \right)^2 P_t y_t \right], \tag{20}$$

where $\Lambda_{0,t}^h \equiv \frac{\beta_h c_0^h}{c_t^h}$ is the households'discount factor. Firms face quadratic adjustment costs á la (Rotemberg (1982)) when adjusting their prices.

3.1.5 Monetary Authority

I assume that the central bank sets the nominal interest rate according to the following Taylor type rule:

$$\frac{1+r_t}{1+r} = \left(\frac{1+r_{t-1}}{1+r} \right)^{\phi_r} \left[\left(\frac{1+\pi_t}{1+\pi} \right)^{\phi_\pi} \left(\frac{y_t}{y_{t-1}} \right)^{\phi_y} \right]^{(1-\phi_r)}, \tag{21}$$

where r and π are the steady state values of the policy rate and inflation. The parameter ϕ_r generates interest-rate smoothing. The coefficients ϕ_π and ϕ_y control how the monetary authority responds to deviations of inflation from its steady state level and to output growth.

3.1.6 Market clearing

The model is closed by combining the first order conditions of all agents with the clearing conditions of the goods and bonds markets:

$$y_t = c_t + [k_t - (1-\delta)k_{t-1}] + \frac{\kappa_p}{2}(\pi_t)^2 y_t, \tag{22}$$

$$s_t = b_t, \tag{23}$$

where $c_t \equiv c_t^h + c_t^e$ is aggregate consumption, k_t is aggregate physical capital, s_t is aggregate loans and b_t is aggregate borrowings.

3.1.7 Shock processes

The uncertainty shocks are modeled with the stochastic volatility approach. Therefore I assume that TFP follows a stationary AR(1) process with heteroskedastic innovations:

$$z_t = (1-\rho_z)z + \rho_z z_{t-1} + \sigma_t^z e_t^z, \quad \text{where } e_t^z \sim \mathcal{N}(0,1). \tag{24}$$

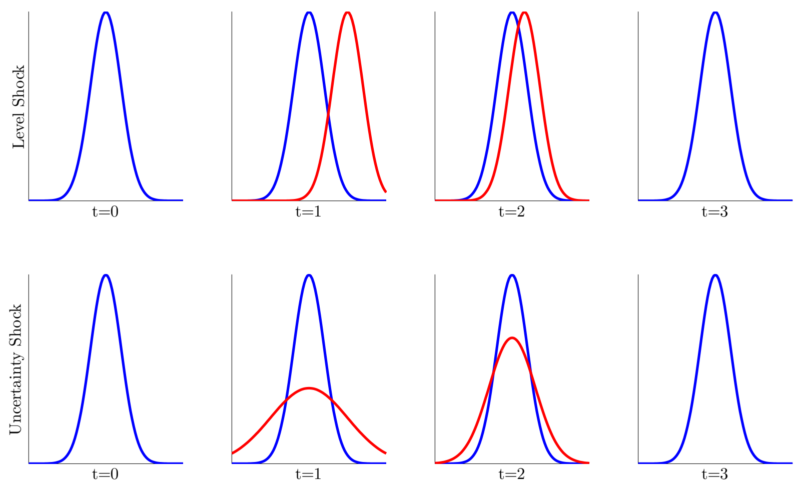
where the coefficient $\rho_z \in (-1,1)$ determines the persistence of the TFP shock and z is the steady state value of TFP. Likewise the conditional standard deviation of the TFP innovations, σ_t^z, follows a stationary AR(1) process:

$$\sigma_t^z = (1-\rho_{\sigma^z})\sigma^z + \rho_{\sigma^z}\sigma_{t-1}^z + \sigma_{\sigma_z} e_t^{\sigma_z}, \quad \text{where } e_t^{\sigma_z} \sim \mathcal{N}(0,1) \tag{25}$$

where σ^z is the steady state value of σ_t^z and the innovation $e_t^{\sigma_z}$ is what I define as uncertainty shock. This shock is assumed to be homoskedastic, i.e. its standard deviation σ_{σ_z} is constant. The parameter ρ_{σ^z} determines the persistence of the uncertainty shock.

Figure 4 compares a shock to the level of TFP with a TFP uncertainty shock. An uncertainty shock is defined as an exogenous increase in the conditional volatility of TFP, while the level of TFP (red point) remains unchanged. An increase in the variance of TFP implies a widening of the tails (red line) of the shock's distribution. Intuitively this means that shocks that can lead to large changes in the level of TFP become more likely. A positive TFP level shock instead, determines a temporary increase in the mean of TFP, i.e. the distribution is temporarily shifted to the right, while its shape remains unchanged.

Figure 4: *Level and uncertainty shock*



Notes: The upper row represents a level shock to TFP that determines a shift in the distribution. The lower row represents a TFP uncertainty shock that determines a widening in the distribution. I assume that the shock lasts for three periods.

3.2 Macroeconomic effects of uncertainty

In order to analyze the effect of the uncertainty shocks, while keeping the first moment shock switched off, we need to approximate the policy function up to a third order[5]. With lower orders of approximation in fact, uncertainty shocks either do not matter or their effects cannot be separated from those of the first moment shocks. With a first order approximation of the policy function, in fact, shocks enter only with their first moments. The first moments of future shocks in turn drop out when taking expectations of the linearized equations. This determines the property of certainty equivalence, i.e. agents do not take into account uncertainty when making their decisions (Schmitt-Grohe and Uribe (2004)). When we instead approximate the policy function to a second order, volatility shocks enter as cross-products with the other state variables (Fernandez-Villaverde et al. (2011a)). We are therefore not able to isolate the effect of the uncertainty shock from that of the first moment shock.

3.2.1 Calibration

The model is calibrated to match quarterly data for the United States. The discount factor for households and entrepreneurs are respectively set to 0.99 and 0.975 as in Iacoviello (2005). The inverse of the Frisch labor supply elasticity is set to 1.0, in line with Christiano et al. (2010). The parameters associated with the external habits formation are set following De Paoli and Zabczyk (2013) (i.e. $\tau = 0.85$ and $\rho_X = 0.97$). The depreciation rate of capital δ is set to 0.025 and the share of capital in the production function α is set to 1/3. The elasticity of substitution between consumption goods ϵ^y is set to 10 (Iacoviello (2005)). The price adjustment parameter κ_p is set equal to 100 (Ireland (2004)). Several parameters are set by following the estimates in Liu et al. (2011) and Iacoviello (2005), for the close resemblance of the models. The investment adjustment costs parameter κ_i is set to 0.19. The LTV ratio m is equal to 0.89. The responses to inflation and output

[5] The model is solved with the algorithm and software developed by Lan and Meyer-Gohde (2013)

growth in the Taylor rule, ϕ_π and ϕ_y are set to 2.0 and 0.3. The interest rate smoothing parameter ρ_r is equal to 0.75. Most parameters related to the shock processes are calibrated similarly to Basu and Bundick (2011). The persistence parameters of the TFP and uncertainty shocks, ρ_z and ρ_{σ^z} are set to 0.9 and 0.83. The steady state value of the TFP shock's standard deviation is equal to 0.01. The standard deviation of the uncertainty shock, σ_{σ_z}, is equal to 0.005, as implied by the empirical evidence.

Table 1: *Parameter values used in the quantitative analysis*

Parameter	Value	Description
Households and Entrepreneurs		
β_h	0.99	Households' discount factor
τ	0.85	Habit size
ρ_X	0.97	Habit persistence
β_e	0.975	Entrepreneurs' discount factor
ϕ	1	Inverse of Frisch labor supply elasticity
δ	0.025	Capital depreciation rate
α	1/3	Output elasticity of capital
ϵ^y	10	Goods elasticity of substitution
κ_i	0.19	Investment adjustment costs
κ_p	100	Price adjustment costs (Rotemberg)
m	0.89	Loan-to-value (LTV) ratio
Monetary Policy		
ϕ^y	0.30	Weight on output in Taylor rule
ϕ^π	2.0	Weight on inflation in Taylor rule
ρ^r	0.75	Interest rate smoothing parameter
Shocks		
σ^z	0.01	Steady state st.dev. of TFP shock
ρ_z	0.9	Persistence of TFP shock
ρ_{σ^z}	0.83	Persistence of uncertainty shock
σ_{σ_z}	0.005	St.dev. of uncertainty shock

3.2.2 The role of external habits

The empirical literature suggests that precautionary savings are countercyclical (see Guiso et al. (2013)). One modeling device that allows to account for these swings in precautionary savings is to include external habit formation (see Cochrane and Campbell (1999) and De Paoli and Zabczyk (2013)). To understand the relationship between external habits and precautionary savings, consider the Euler equation that can be derived from the household's maximization problem:

$$1 = (1 + r_t)\mathbb{E}_t\Lambda^h_{t,t+1} \tag{26}$$

where $\Lambda^h_{t,t+1}$ is the households' stochastic discount factor:

$$\Lambda^h_{t,t+1} \equiv \frac{\beta_h \log\left(c^h_{t+1} - \tau X^h_{t+1}\right)}{\log\left(c^h_t - \tau X^h_t\right)}. \tag{27}$$

Consider a second-order approximation of (26) around the steady state. Under log-normality of $\Lambda^h_{t,t+1}$, (26) can be written as:

$$-r_t = \mathbb{E}_t\lambda^h_{t,t+1} + 0.5\,\mathrm{var}_t\left(\lambda^h_{t,t+1}\right), \tag{28}$$

where $\lambda^h_{t,t+1}$ is the logarithmic deviation of the stochastic discount factor from its steady state value. Notice that (26) can be approximated by (28) only under the assumption that r_t has zero variance and is uncorrelated with $\Lambda^h_{t,t+1}$. The first term in (28) represents the intertemporal substitution effect, while the second term is the precautionary savings effect. Precautionary savings, $\mathrm{var}_t\left(\lambda^h_{t,t+1}\right)$, depend on the overall level of macroeconomic volatility, on investors' risk aversion and on current and past economic conditions (De Paoli and Zabczyk (2013)). Hence we can write:

$$\mathrm{var}_t\left(\lambda^h_{t,t+1}\right) = \phi\left(\sigma^z_t, \psi, x_t, e^z_t\right), \tag{29}$$

where ϕ is a function of the time-varying macroeconomic volatility σ_t^z, consumers' risk-aversion coefficient ψ (that is equal to one given the log-utility assumption) and past and current economic conditions, summarized by the state variable x_t (i.e. the log-linear deviation of the external habit X_t from its steady state value) and the shock e_t^z. Nevertheless the latter is switched off when the uncertainty shock hits the model economy, therefore we can simplify (29) to:

$$\mathrm{var}_t\left(\lambda_{t,t+1}^h\right) = \phi\left(\sigma_t^z, \psi, x_t\right). \tag{30}$$

When external habits are excluded from the model, precautionary savings depend only on macroeconomic volatility and consumers' risk aversion:

$$\mathrm{var}_t\left(\lambda_{t,t+1}^h\right) = \phi\left(\sigma_t^z, \psi\right) \tag{31}$$

Hence, if we introduce external habits, precautionary savings will depend on an additional factor, namely on current and past economic conditions and will vary cyclically with the state of the economy.

3.2.3 Results

I now analyze the effects of an uncertainty shock to TFP on the main macroeconomic aggregates by means of IRFs. The goal is to assess the importance of cyclical changes in precautionary savings in explaining the strong asymmetric effects found in the data[6]. Therefore I compare the baseline model with external habits (EH) to one with a smaller weight ($\tau = 0.425$) on the external habits (SEH) and one with no external habits (NEH). Figure 5 displays the IRFs of a one-standard deviation TFP uncertainty shock for all three

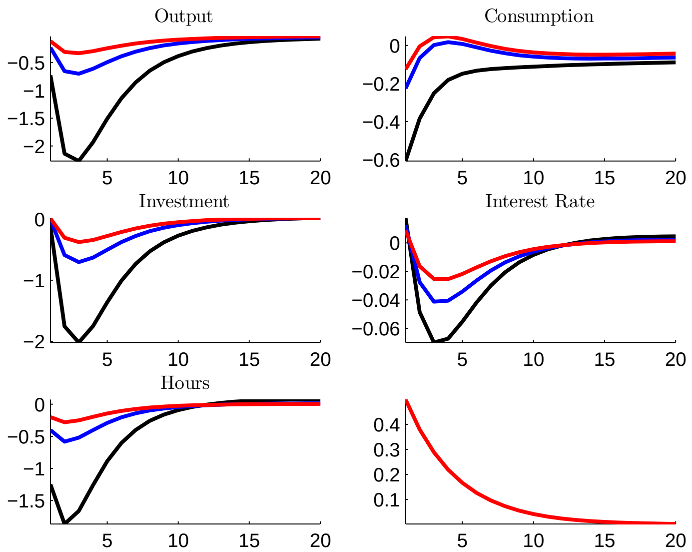
[6] Figure 6 in the appendix displays the effect of relaxing the borrowing constraint, i.e. the effect of increasing the LTV parameter. The figure shows that the constraint somewhat amplifies the macroeconomic effects of the uncertainty shock, but not as much as the change in the habit parameter. Moreover the fall in the main macroeconomic aggregates seems proportional to reduction in the LTV parameter. This suggests that this friction does not explain the asymmetric effects of uncertainty shocks that I found in the data.

specifications of the model. In particular the red line represents the NEH model, the blue line represents the SEH, and finally the black line represents the EH model.

Similarly as in the empirical part, output, consumption, investment fall after the TFP uncertainty shock hits the economy. The sticky-prices assumption is crucial in order to obtain the negative co-movement (Basu and Bundick (2011)). After an uncertainty shock, individuals reduce consumption and increase labour supply for precautionary reasons. Since retailers cannot adjust their prices, these cannot fall as much as the marginal costs, which leads to a rise in markups. As a consequence of the increase in markups, labour demand falls and in equilibrium hours worked decline. In turn output and investment fall. The pattern depicted in Figure 5 also confirms the finding of Leduc and Liu (2012) that uncertainty shocks act as negative demand shocks. Just like negative aggregate demand shocks, uncertainty shocks lead to a fall in output and prices (that is implied by the fall in the interest rate).

The effect of including external habits can be seen by comparing the three different specifications of the model. The first result is that macroeconomic aggregates react more strongly to the TFP uncertainty shock once we include external habit formation. Consumption falls nearly six times more in the EH case than in the NEH. Similar patterns occur for all the variables displayed. This occurs because, as mentioned in subsection 3.2.2, in EH and SEH precautionary savings depend additionally on past and current economic conditions. Specifically, in NEH precautionary savings increase solely because of the rise in macroeconomic uncertainty. This can be seen as the direct effect of the uncertainty shock, which leads to a sluggish fall in economic activity. In EH and SEH instead, there is an additional "feedback" effect. The economic downturn due the increase in macroeconomic uncertainty causes precautionary savings to rise even further. This leads to larger drops in consumption, investment, labour demand (hence equilibrium hours) and output compared to the NEH case. Another insightful result that we can draw by taking a closer look at the IRFs is that the "feedback" effect is nonlinear. This can be seen by comparing the transitions from NEH to EH and from SEH to EH. In particular the falls in output, consumption and investment are more than proportional compared to the change in the habit parameter τ. When we pass from NEH to SEH, by increasing τ from 0 to 0.425, we have that the drop in consumption nearly doubles, and similarly for investment and output. When we pass to EH, increasing τ by 0.425 compared to SEH, the drops in consumption, investment and output are roughly three times larger than in SEH. In other words, the fall in the macroeconomic aggregates becomes larger when we pass from SEH to EH compared to the transition from NEH to SEH, although the change in the habit parameter τ remains the same.

Figure 5: *Impulse responses to a shock in TFP uncertainty*



Notes: Black line: EH model; Blue line: SEH model; Red line: NEH model; All variables are expressed in percentage deviations from steady state.

To sum up, the quantitative analysis shows that allowing precautionary savings to depend on cyclical economic conditions considerably amplifies the macroeconomic effects of uncertainty shocks. Furthermore the "feedback effect" is quantitatively more relevant than the pure direct of increasing macroeconomic uncertainty. A closer look at the IRFs also shows that by increasing the habit parameter τ, the uncertainty shocks induce a more than proportional fall in the main macroeconomic variables. This suggests that the asymmetric effects found in section 2 could largely be driven by countercyclical changes in precautionary savings. Namely, an uncertainty shock hitting the economy during a recessionary regime raises precautionary savings more than in normal times because agents take into account the past and current economic conditions. The outcomes of the model are qualitatively and quantitatively in line with the empirical findings in section 2. Specifically, in the EH case I am able to reproduce similar patterns of consumption and investment as in the recessionary regime of the STVAR model.

4 Concluding remarks

Uncertainty is considered to have particularly severe effects when the economy is in a recessionary phase. The present paper sheds light on the asymmetric macroeconomic effects of uncertainty shocks, providing empirical evidence and a theoretical explanation. To this end, I first estimate a Smooth Transition VAR model for the US economy and find that during recessions uncertainty shocks have significant dampening effects on economic activity. In particular, investment and consumption fall twice as much as a standard linear VAR would imply. Secondly, I employ a New-Keynesian DSGE model that features heterogeneous agents, households (savers) and entrepreneurs (borrowers), to show that the asymmetric effects of uncertainty shocks can be driven by countercyclical fluctuations in precautionary savings. I account for these fluctuations by introducing persistent external habits into the consumers' utility function. As explained by De Paoli and Zabczyk (2013), the inclusion of external habits leads precautionary savings to depend not only on aggregate macroeconomic uncertainty and on the risk aversion parameter, but also on the past and current state of the economy. Thereby uncertainty shocks increase precautionary savings by directly raising macroeconomic uncertainty (direct effect) and indirectly by dampening economic conditions (feedback effect). When we allow precautionary savings to vary over the cycle, the results of the DSGE model show that uncertainty shocks have considerable contractionary effects, in line with the empirical evidence. Moreover I find that the feedback effect is strongly nonlinear, quantitatively more relevant than the pure direct effect of increasing macroeconomic uncertainty and plays an important role in reconciling the evidence provided in the empirical analysis and the results of the theoretical model.

5 Appendix 1: First order conditions

5.1 First order conditions of the households

First order condition with respect to consumption

$$\lambda_t = \frac{1}{c_t^h - \tau X_t^h} \tag{32}$$

Households' Euler equation

$$\lambda_t = \beta_h \mathbb{E}_t \left[\lambda_{t+1} \frac{(1 + r_t)}{(1 + \pi_{t+1})} \right], \tag{33}$$

Labor supply equation

$$n_t^\phi = w_t \lambda_t, \tag{34}$$

Households' budget constraint

$$c_t^h + s_t = w_t n_t + (1 + r_{t-1}) \frac{d_{t-1}}{(1 + \pi_t)} + J_t^R, \tag{35}$$

5.2 First order conditions entrepreneurs

$$s_t m \mathbb{E}_t (1 + \pi_{t+1})(1 - \delta) + \beta_e \mathbb{E}_t \left[\left(\frac{1}{c_{t+1}^e} \right) \left((1 - \delta) + r_{t+1} \right) \right] = \frac{1}{c_t^e}, \tag{36}$$

Wage equation

$$w_t = (1 - \alpha) \frac{y_t^e}{n_t x_t}, \tag{37}$$

Euler equation entrepreneurs

$$\frac{1}{c_t^e} - s_t (1 + r_t) = \beta_e \mathbb{E}_t \left[\frac{1}{c_{t+1}^e} \frac{(1 + r_t)}{(1 + \pi_{t+1})} \right], \tag{38}$$

Budget constraint entrepreneurs

$$c_t^e + \left(\frac{(1 + r_{t-1})b_{t-1}}{1 + \pi_t} \right) + w_t n_t + q_t^k k_t = \frac{y_t^e}{x_t} + b_t + q_t^k (1 - \delta) k_{t-1}, \tag{39}$$

Production function

$$y_t^e = z_t \left(k_{t-1} \right)^{\alpha} n_t^{1-\alpha}, \tag{40}$$

Borrowing constraint

$$(1 + r_t)b_t = m\mathbb{E}_t \Big[q_{t+1}^k (1 + \pi_{t+1}) k_t (1 - \delta) \Big], \tag{41}$$

5.3 Capital producers

Return on capital

$$r_t^k = \frac{\alpha a_t \left(k_{t-1} \right)^{\alpha-1} l_t^{1-\alpha}}{x_t}, \tag{42}$$

Capital equation

$$k_t = (1 - \delta) k_{t-1} + \left[1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right] i_t, \tag{43}$$

5.4 Retailers

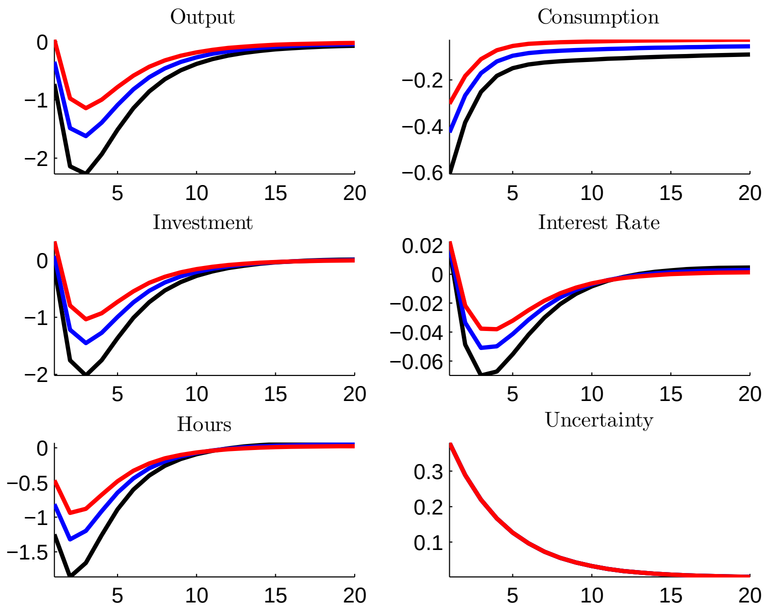
$$J_t^R = y_t \left(1 - \frac{1}{x_t} - \frac{\kappa_p}{2} \pi_t^2 \right), \tag{44}$$

Nonlinear Phillips curve

$$\begin{aligned} & 1 - \epsilon_t^y + \frac{\epsilon_t^y}{x_t} - \kappa_p \pi_t (1 + \pi_t) \\ & + \beta_h \mathbb{E}_t \left[\frac{c_t^h}{c_{t+1}^h} \kappa_p \pi_{t+1} (1 + \pi_{t+1}) \frac{y_{t+1}}{y_t} \right] = 0, \end{aligned} \tag{45}$$

6 Appendix 2: Relaxing the borrowing constraint

Figure 6: *Impulse responses to a shock in TFP uncertainty*



Notes: Black line: baseline loan to value ratio $m = 0.85$; Blue line: medium loan to value ratio $m = 0.9$; Red line: loose loan to value ratio $m = 0.95$. All variables are expressed in percentage deviations from steady state.

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