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Macroeconomic Effects of Financial Uncertainty

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Macroeconomic Effects of Financial Uncertainty^{*}

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Abstract

This paper investigates the macroeconomic effects of uncertainty originating in the financial sector. My contribution is twofold. First, I document empirical relevance of financial uncertainty using SVAR methods. Then, I employ the DSGE framework developed by Gertler and Karadi (2011) to uncover the underlying transmission mechanism. The model generates macroeconomic dynamics that are consistent with the SVAR evidence. In particular, an increase in financial uncertainty raises the risk premium and leads to a decline in output, consumption, investment and hours worked. This outcome arises mainly because of an endogenous tightening of the financial constraint, which in turn triggers the financial accelerator mechanism. Finally, internal habit formation and nominal rigidities act as additional amplification mechanisms for financial uncertainty shocks.

Keywords: Stochastic Volatility, Financial Frictions, Financial Uncertainty

JEL Classification Numbers: E44, E32, E21

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1 Introduction

There exists a rapidly growing literature on the macroeconomic implications of uncertainty shocks. Interest in this topic has been sparked by the robust observation that uncertainty rises in recessions (see, e.g., Bloom, 2009, Jurado et al., 2015). The DSGE literature focuses on real economic uncertainty, i.e., uncertainty surrounding economic fundamentals, such as total factor productivity or economic policy.¹ This is also true for studies assessing the role of financial frictions as a propagator of economic uncertainty.² However, Ng and Wright (2013) document that all post-1982 U.S. recessions have origins in the financial markets. In addition, Ludvigson et al. (2015) provide empirical evidence that movements in financial market uncertainty are an important source of economic fluctuations rather than an endogenous response to fundamentals. The authors conclude their analysis with the following statement:

[...] These findings point to the need for a better understanding of how uncertainties in financial markets are transmitted to the macroeconomy.

The aim of this study is to contribute to the existing literature by investigating the macroeconomic implications and transmission mechanism of financial uncertainty, i.e., uncertainty originating from the financial sector. My contribution is twofold. First, I estimate a Structural Vector Autoregressive (SVAR) model and provide evidence that an increase in financial uncertainty has an adverse effect on main macroeconomic aggregates, such as GDP, consumption, investment and hours worked. Second, to uncover the transmission mechanism of financial uncertainty shocks, I introduce time-varying volatility

¹The DSGE literature investigates a variety of real uncertainty shocks. Caldara et al. (2012) consider total factor productivity in a model with recursive preferences, whereas Fernández-Villaverde et al. (2011) focus on the foreign interest rate in a small-open economy setup. Moreover, Mumtaz and Zanetti (2013) look at monetary policy uncertainty, while Born and Pfeifer (2014) investigate the contribution of monetary and fiscal uncertainty to the economic fluctuations in the United States. Finally, Basu and Bundick (2017) investigate uncertainty associated with the aggregate demand and argue that nominal rigidities are key to generate co-movement among macroeconomic aggregates following a rise in uncertainty.

²See, among others, Christiano et al. (2014), Gilchrist et al. (2014), Arellano et al. (2016) and Bonciani and Van Roye (2016).

of financial disturbances into the DSGE model developed by Gertler and Karadi (2011). Since this framework embeds financial intermediaries operating under funding constraints, it is suitable to investigate the effects of uncertainty regarding disturbances originating in the financial sector. This financial (level) disturbance is modeled as a shock to the survival probability of financial intermediaries. The model is able to generate dynamics of the macroeconomic variables that are consistent with the empirical evidence. In particular, output, investment, consumption and hours worked drop while the risk premium rises in response to an increase in financial uncertainty. The key feature of the model responsible for this outcome is the tightening of the endogenous leverage constraint, which in turn triggers the financial accelerator mechanism. Specifically, due to an increase in financial uncertainty, households provide less funding to financial intermediaries. This reduces aggregate investment and thus asset prices fall. As a consequence, the financial position of the intermediaries deteriorates even further, which forces them to reduce their lending again. Simultaneously, under the assumption of internal habit formation and sticky prices, aggregate consumption falls. Thereby, these model features act as additional amplification mechanisms for financial uncertainty shocks. Finally, I use the theoretical framework to compare the effects of financial uncertainty shocks with the consequences of macroeconomic uncertainty in the underlying framework. While both types of uncertainty have qualitatively similar effects on economic activity, their key propagation mechanisms differ. In particular, macro uncertainty relies more extensively on nominal and real rigidities.

This study is strongly related to the work of Ludvigson et al. (2015). These authors construct a novel measure of financial uncertainty and conduct an empirical investigation by employing correlation and event constraints. They find evidence that financial uncertainty is a likely source of economic fluctuations, while fluctuations in macroeconomic uncertainty seem to be an endogenous response to other economic disturbances. While this idea underlies both my empirical and theoretical analysis, my empirical anal-

ysis differs from their study in two respects. First, as I neglect macroeconomic uncertainty and focus solely on financial uncertainty, I identify uncertainty shocks by using a Cholesky decomposition. Second, Ludvigson et al. (2015) investigate only effects of financial uncertainty on the industrial production, whereas I include further macroeconomic aggregates, a measure of risk premium, and a measure of monetary policy stance in the SVAR model.

To the extent of my knowledge, there is one contribution by Richter and Throckmorton (2018) introducing financial uncertainty shocks into a DSGE model. The authors develop a new method to quantify the effects of different types of uncertainty using estimates from a nonlinear DSGE model. This approach allows them to decompose the exogenous and endogenous sources of uncertainty. However, their focus does not lie on the propagation mechanism of financial uncertainty per se. Therefore, they use a textbook New Keynesian model which does not include an explicit financial sector and financial uncertainty is related to a second-moment shock to the return on a nominal bond. In contrast, I use a richer framework with a microfounded banking sector and real rigidities which allows to me to assess the importance of various transmission channels.

The rest of the paper is organized as follows. In section 2, I provide empirical evidence on macroeconomic effects of financial uncertainty. The theoretical model is outlined in section 3. In section 4, I discuss the chosen calibration and the method used to solve the model. Section 5 presents the results. In particular, I document the dynamics implied by the model and assess the importance of various features of the framework for the transmission mechanism. Finally, section 6 concludes.

2 Empirical Evidence

To provide empirical evidence on the relevance of financial uncertainty for economic fluctuations, I estimate a VAR model using quarterly U.S. data for the period 1986:Q1-2016:Q4. The structural model is given by

$$A_0 y_t = A_1 y_{t-1} + \dots + A_{t-p} y_{t-p} + \epsilon_t, \quad (1)$$

where y_t is an $n \times 1$ vector of variables of interest and $\epsilon_t \sim \mathcal{N}(0, I_n)$. The corresponding reduced-form VAR can then be written as

$$y_t = B_1 y_{t-1} + \dots + B_p y_{t-p} + u_t, \quad (2)$$

with $B_j \equiv A_0^{-1} A_j$ and $u_t \equiv A_0^{-1} \epsilon_t \sim \mathcal{N}(0, \Sigma_u)$.

I include eight variables in the estimation: 1) a measure of financial uncertainty (*FinUnc*), 2) per capita real GDP (Y), 3) per capita consumption (C), 4) per capita investment (I), 5) hours worked (L), 6) inflation rate (π), measured as the percentage change of the GDP implicit price deflator, 7) risk premium (*spr*), measured by the difference between BAA corporate bond yield and 10 year treasury yield, 8) and finally the federal funds rate (*EFFR*).³ A detailed description of the data can be found in Appendix A. All variables except the inflation rate, the risk premium and the federal funds rate enter the VAR in log levels. Finally, all variables are detrended by applying the HP filter with a smoothing parameter of 1600.

The proxy for financial uncertainty is taken from Ludvigson et al. (2015). Following the framework of Jurado et al. (2015), this measure aggregates a large number of estimated uncertainties constructed from a rich data set including a variety of finan-

³The results presented below do not substantially change if the BBA spread is replaced by the credit spread constructed by Gilchrist and Zakrajšek (2012). They are also robust to measuring the stance of monetary policy by the shadow rate developed by Wu and Xia (2016).

cial indicators. In particular, underlying financial data consist of 148 series and include dividend-price ratios, yield-spreads, a broad cross-section of equity returns as well as various measures of variation in the market risk premium. Uncertainty associated with an individual series x_t is defined as the volatility of its h -period ahead forecast error (Ludvigson et al., 2015)

$$U_x(h) \equiv \sqrt{E_t \left[(x_{t+h} - E_t[x_{t+h}])^2 \right]}, \quad (3)$$

where E_t denotes the expectation operator given the information set in period t .⁴ As argued by Jurado et al. (2015), the advantage of uncertainty measures based on forecast errors is that they can truly capture the degree to which the economy has become more or less predictable, i.e., uncertain. In contrast, other existing proxies reflect rather time-varying dispersion or volatility of the economic indicators. Moreover, they can often provide misleading information. For example, stock market volatility can fluctuate even if uncertainty remains constant due to changes in investors' risk aversion or sentiment.

Following a large body of empirical literature, financial uncertainty shocks are identified using a Cholesky decomposition.⁵ The measure of financial uncertainty is ordered first and is followed by the macroeconomic aggregates, the risk premium and the federal funds rate, i.e., $y_t = [FinUnc_t, Y_t, C_t, I_t, L_t, \pi_t, spr_t, EFR_t]'$. This ordering is consistent with the theoretical model discussed in section 3 and the underlying intuition is in line with the main findings of Ludvigson et al. (2015).

I estimate the model up to four lags and determine the appropriate specification by using the Bayesian information criterion, according to which the data prefers the model with one lag. Figure 1 plots the impulse responses to an identified financial uncertainty shock along with the 95 % confidence intervals. A one-standard-deviation increase in

⁴The data set constructed by Ludvigson et al. (2015) include three different forecast horizons: one month, one quarter and one year. In the following, I use quarterly forecasts to match the frequency of the time series used in the estimation.

⁵See, among others, Bloom (2009), Bachmann and Bayer (2013), Jurado et al. (2015), Baker et al. (2016) and Basu and Bundick (2017).

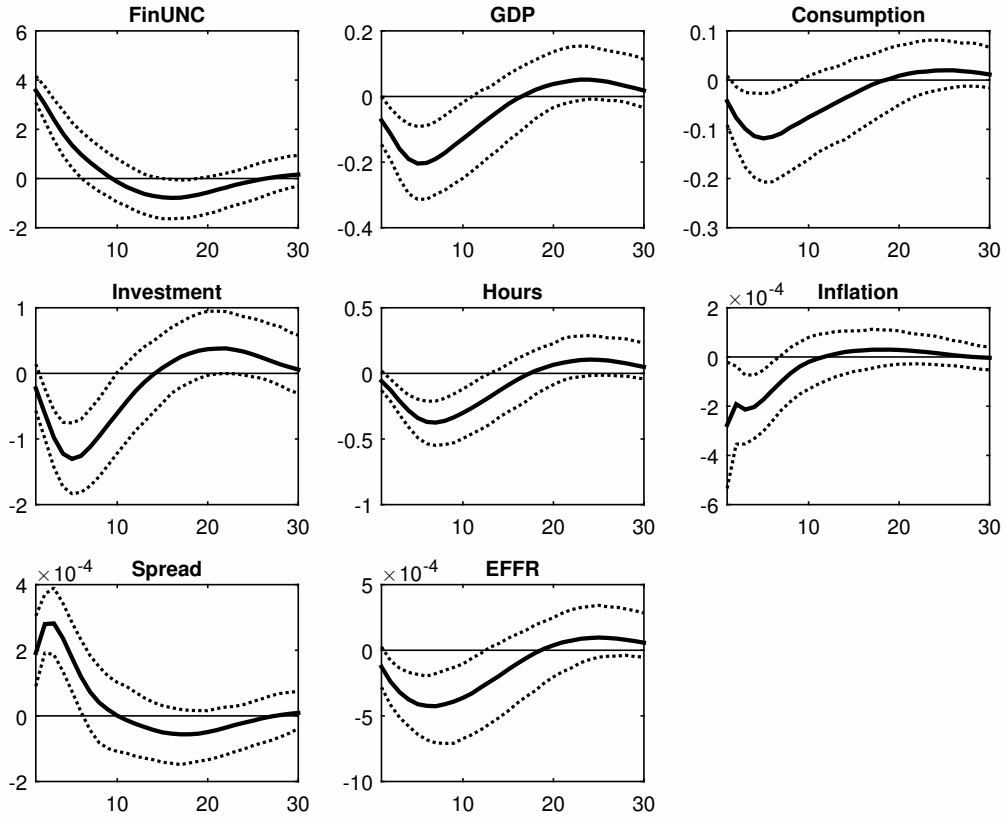


Figure 1: Dynamic consequences of one-standard-deviation increase in financial uncertainty. Horizontal axes indicate quarters. The solid curve denotes the median response, whereas the dotted curves refer to the 95 % confidence interval. Responses of all variables except inflation, the risk premium and the federal funds rate are in percent.

financial uncertainty leads to tighter financial conditions in the economy, as shown by the rise in the risk premium. It also leads to statistically significant declines in output, consumption, investment and hours worked. The peak response occurs after about a year and amounts in case of the GDP to a drop of 0.21%. The subsequent recovery is followed by a rebound - a phenomenon labeled by Bloom (2009) as *volatility overshoot*. For example, in case of the GDP the overshoot arises after about four years.

To assess the robustness of the VAR evidence, I modify the estimation exercise in several ways. First, I use an alternative ordering with the measure of financial uncertainty ordered last. Second, following Caldara et al. (2016), I use the Chicago Board

Options Exchange S&P 100 Volatility Index (VXO) as a proxy for financial uncertainty.⁶ Finally, I extend the set of variables by including a measure of macroeconomic uncertainty constructed by Jurado et al. (2015). It is based on 132 time series of macroeconomic indicators ranging from real output and income to inventories and capacity utilization measures. As shown in Appendix B, the results obtained under these alternative specifications do not substantially differ from the ones of the benchmark estimation. Hence, I provide a robust evidence that an adverse financial uncertainty shock results in a higher risk premium and a decline in economic activity as reflected by the decrease in GDP, consumption, investment and hours worked.

3 The Model

To shed light on the transmission mechanism of uncertainty shocks originating in the financial sector, I employ the New Keynesian model with financial frictions developed by Gertler and Karadi (2011). One period corresponds to one quarter and there are six types of agents in the model: households, financial intermediaries, intermediate goods producers, monopolistically competitive retailers, capital producers and a central bank, whose actions are described by a standard Taylor-rule.

3.1 Households

There exists a continuum of identical households of unity mass. Within each household, there are $1 - f$ workers and f bankers. Workers supply labor and earn wages, whereas each banker manages a financial intermediary and accumulates funds ("net worth") which she transfers to the household upon exiting the business. To merge the within-household heterogeneity with the representative agent framework, I assume that there is perfect consumption sharing within each family.

⁶Since VXO corresponds to the option-implied volatility, it can be related to financial markets. However, as discussed before, it may be capturing factors unrelated to movements in financial uncertainty.

Household's preferences are given by

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - hC_{t-1})^{1-\gamma} - 1}{1-\gamma} - \frac{\chi}{1+\varphi} L_t^{1+\varphi} \right], \quad (4)$$

where C_t denotes consumption and L_t is labor supply. Moreover, $\beta \in (0, 1)$ refers to the discount factor, $h \in (0, 1)$ is parameter governing internal habit formation and γ represents the inverse of the intertemporal elasticity of substitution. Finally, φ is the inverse of the Frish elasticity of labor supply and χ denotes the weight of the disutility of labor supply.

Households do not have a direct access to the capital stock. Rather, they save by depositing funds at financial intermediaries.⁷ Bank deposits, denoted by D_t , are equivalent to one period real riskless bonds yielding gross real rate of return R_{t-1} from $t-1$ to t . The budget constraint faced by the household is thus given by

$$C_t + D_t = W_t L_t + R_{t-1} D_{t-1} + T_t, \quad (5)$$

where W_t refers to the real wage and T_t are net profits from the ownership of both non-financial firms and financial intermediaries. Let U_{Ct} denote the marginal utility of consumption and $\Lambda_{t,t+1}$ the household's stochastic discount factor. Then maximizing the life-time utility with respect to consumption, labor and savings subject to the flow of funds constraint (5) yields the following first-order conditions

$$W_t U_{Ct} = \chi L_t^\varphi, \quad (6)$$

with $U_{Ct} = (C_t - hC_{t-1})^{-\gamma} - \beta h E_t [(C_{t+1} - hC_t)^{-\gamma}]$ and

$$E_t [\Lambda_{t,t+1}] R_t = 1, \quad (7)$$

⁷The implicit assumption is that households supply funds to banks other than the ones they own.

with $\Lambda_{t,t+1} \equiv \beta \frac{U_{Ct+1}}{U_{Ct}}$.

3.2 Nonfinancial Firms

There are three types of nonfinancial firms: intermediate goods producers, monopolistically competitive retailers and capital producers.

Intermediate Goods Producers

In period t competitive firms with identical constant returns to scale technology produce intermediate goods, Y_{mt} , by combining capital stock purchased at the end of period $t - 1$, K_{t-1} , and labor, L_t , and by varying the utilization rate of capital U_t . This process is governed by the following Cobb-Douglas production function

$$Y_{mt} = A_t (\xi_t U_t K_{t-1})^\alpha L_t^{1-\alpha}, \quad (8)$$

where $\alpha \in (0, 1)$, A_t denotes the exogenously given technology level and ξ_t refers to the capital quality shock.⁸ There are no adjustment costs at the firm level and thus the intermediate producer's maximization problem is static. In particular, at the end of each period, the firm replaces the depreciated capital, sells its entire capital stock and purchases capital that will be employed in the subsequent period. Following Gertler and Karadi (2011), I assume that the replacement price of used capital is equal to unity.⁹ As a result, the decision with respect to capital utilization is independent of the price of capital.

To finance capital acquisition, the firm must obtain funds from financial intermediaries. To this end, it issues state contingent claims in the amount equal to the number of purchased capital units. Thus, arbitrage requires that these claims are traded at the price of a unit of capital, Q_t . Given that R_k denotes the gross real interest rate paid on state

⁸See, among others, Gertler and Kiyotaki (2010), Gertler and Karadi (2011) and Dedola et al. (2013).

⁹ This requires that the adjustment costs are on net investment. See the description of capital producers.

contingent securities, the intermediate good producer chooses labor input and capital utilization to maximize her current profits

$$P_{mt}Y_{mt} + [Q_t - \delta(U_t)] \xi_t K_{t-1} - W_t L_t - R_{kt} Q_{t-1} K_{t-1}, \quad (9)$$

where P_{mt} denotes the price of intermediate goods relative to the final consumption good and $\delta(U_t) = \delta_0 + \frac{\delta_1}{1+\delta_2} U_t^{1+\delta_2}$, with $\delta_0, \delta_1, \delta_2 > 0$, is the depreciation rate being a function of capital utilization. Solving this maximization problem yields the following first-order conditions

$$W_t = P_{mt} (1 - \alpha) \frac{Y_{mt}}{L_t}, \quad (10)$$

and

$$\alpha P_{mt} \frac{Y_{mt}}{U_t} = \delta' (U_t) \xi_t K_t. \quad (11)$$

Note that under assumptions of competitive firms and constant returns to scale, the intermediate producers make zero profits in equilibrium. Thus, the ex-post rate of return on state contingent assets is given by

$$R_{kt} = \frac{\alpha P_{mt} A_t \xi_t^\alpha K_{t-1}^{\alpha-1} L_t^{1-\alpha} + [Q_t - \delta(U_t)] \xi_t}{Q_{t-1}}. \quad (12)$$

Retailers

There exists a continuum of mass unity of monopolistically competitive retailers who repackage the intermediate output. They require one unit of the intermediate good to produce one unit of the retailer output. Hence, the marginal cost of the final good production is simply P_{mt} .

Final output, Y_t , is given by the CES aggregator of differentiated retailer goods, Y_{it} ,

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{q-1}{q}} di \right]^{\frac{q}{q-1}}, \quad (13)$$

where $\varrho > 1$ is the elasticity of substitution between different retailer goods. Cost minimization by the final output user yields

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\varrho} Y_t, \quad (14)$$

and

$$P_t = \left[\int_0^1 P_{it}^{1-\varrho} di \right]^{\frac{1}{1-\varrho}}. \quad (15)$$

Retailers face nominal rigidities à la Calvo (1983).¹⁰ In particular, each period a retailer is able to adjust her prices with probability $1 - \theta_{calvo}$. Therefore, a retailer, updating her price in period t , chooses the reset price, P_t^* , that maximizes the present value of profits generated while the price remains valid¹¹

$$\max E_t \left[\sum_{k=0}^{\infty} \theta_{calvo}^k \Lambda_{t,t+k} \left(\frac{P_t^*}{P_{t+k}} - P_{mt+k} \right) Y_{it+k} \right]. \quad (16)$$

The corresponding first-order condition is given by

$$E_t \left[\sum_{k=0}^{\infty} \theta_{calvo}^k \Lambda_{t,t+k} \left(\frac{P_t^*}{P_{t+k}} - \frac{\varrho - 1}{\varrho} P_{mt+k} \right) \left(\frac{P_t^*}{P_{t+k}} \right)^{-\varrho} Y_{it+k} \right] = 0. \quad (17)$$

By rearranging (17) one can obtain the following relationship

$$\Pi_t^* = \frac{\varrho}{\varrho - 1} \frac{X_{1,t}}{X_{2,t}} \Pi_t, \quad (18)$$

¹⁰Note that the heterogeneity introduced by the Calvo assumption may in general require tracking distributions when the model is solved with a higher-order perturbation (Born and Pfeifer, 2014). However, this is not the case in the underlying framework. The reason for this is that retailers only repack goods and update their prices, whenever this is possible. They do not make any further decisions, especially regarding factors of production.

¹¹In the original model of Gertler and Karadi (2011), the retailers are able to index their prices to the lagged rate of inflation. I omit this feature for simplicity, as it virtually does not affect the transmission of financial uncertainty shocks.

with $\Pi_t^* \equiv \frac{P_t^*}{P_{t-1}}$ and $\Pi_t \equiv \frac{P_t}{P_{t-1}}$. $X_{1,t}$ and $X_{2,t}$ are defined recursively as:

$$X_{1,t} = Y_t P_{mt} + \theta_{calvo} E_t [\Lambda_{t,t+1} \Pi_{t+1}^\varrho X_{1,t+1}] , \quad (19)$$

and

$$X_{2,t} = Y_t + \theta_{calvo} E_t [\Lambda_{t,t+1} \Pi_{t+1}^{\varrho-1} X_{2,t+1}] . \quad (20)$$

The relationship between aggregate final output and aggregate intermediate production can be written as

$$Y_t = Y_{mt} \Delta_{pt} , \quad (21)$$

where Δ_{pt} is the dispersion of individual prices. Its law of motion is given by

$$\Delta_{pt} = \theta_{calvo} \Delta_{pt-1} \Pi_t^\varrho + (1 - \theta_{calvo}) \left(\frac{\Pi_t^*}{\Pi_t} \right)^{-\varrho} . \quad (22)$$

Moreover, under the Calvo assumption and given the aggregate price index (15), the inflation rate can be expressed as

$$\Pi_t^{1-\varrho} = (1 - \theta_{calvo}) (\Pi_t^*)^{1-\varrho} . \quad (23)$$

Finally, note that since P_{mt} represents the price of the intermediate goods relative to the final output, the markup of monopolistic retailers, X_t , is its inverse:

$$X_t = \frac{1}{P_{mt}} . \quad (24)$$

Capital Producers

Competitive capital producers replace the depreciated capital and produce new investment goods. Thus, the total investment is given by $I_t = I_{nt} + \delta(U_t) \zeta_t K_{t-1}$, where I_{nt} denotes the net investment. To generate time-variation in the price of capital, I introduce

investment adjustment cost into the model. Following Gertler and Karadi (2011), capital producers face adjustment costs associated only with producing new capital. In contrast, there are no such costs for refurbishing old capital stock. Consequently, the costs of replacing depreciated capital stock are fixed to unity.

The capital producers choose I_{nt} that maximizes expected lifetime profits given by

$$E_t \left[\sum_{k=0}^{\infty} \Lambda_{t,t+k} \left((Q_{t+k} - 1)I_{nt+k} - f_{inv} \left(\frac{I_{nt+k} + I_{SS}}{I_{nt+k-1} + I_{SS}} \right) (I_{nt+k} + I_{SS}) \right) \right], \quad (25)$$

with I_{SS} denoting the investment in the deterministic steady state and $f_{inv} \left(\frac{I_{nt} + I_{SS}}{I_{nt-1} + I_{SS}} \right) = \frac{\eta}{2} \left(\frac{I_{nt} + I_{SS}}{I_{nt-1} + I_{SS}} - 1 \right)^2$. The corresponding first-order condition determines the price of one unit of capital

$$\begin{aligned} Q_t = 1 + \frac{\eta}{2} \left(\frac{I_{nt} + I_{SS}}{I_{nt-1} + I_{SS}} - 1 \right)^2 \\ + \eta \left(\frac{I_{nt} + I_{SS}}{I_{nt-1} + I_{SS}} - 1 \right) \frac{I_{nt} + I_{SS}}{I_{nt-1} + I_{SS}} - \eta E_t \left[\Lambda_{t,t+1} \left(\frac{I_{nt+1} + I_{SS}}{I_{nt} + I_{SS}} - 1 \right) \left(\frac{I_{nt+1} + I_{SS}}{I_{nt} + I_{SS}} \right)^2 \right]. \end{aligned} \quad (26)$$

Finally, note that capital producers can earn non-zero profits outside of the steady state. These profits are assumed to be redistributed lump sum to households.

3.3 Financial Intermediaries

Financial intermediaries (or banks) provide funds to producers of intermediate goods. Their operations are financed by a combination of deposits, D_t , held by households, and their own net worth, N_t , which is accumulated from retained earnings. Hence, the balance sheet of the financial intermediary j is given by

$$Q_t K_{jt} = D_{jt} + N_{jt}. \quad (27)$$

As noted above, deposits made with the bank at time t pay the non-contingent real gross return R_t in the subsequent period. In contrast, assets held by the intermediary earn the stochastic return R_{kt+1} over the same period. Then, the law of motion for the net worth of the intermediary j is given by

$$\begin{aligned} N_{jt} &= R_{kt} Q_{t-1} K_{jt-1} - R_{t-1} D_{jt-1} \\ &= (R_{kt} - R_{t-1}) Q_{t-1} K_{jt-1} + R_{t-1} N_{jt-1}, \end{aligned} \quad (28)$$

where the second equality follows from the balance sheet condition.

The intermediary has an incentive to operate in period t only if the expected discounted rate of return on assets does not lie below costs of borrowing. By applying the household's discount factor, this condition can be written as

$$E_t [\Lambda_{t,t+1} (R_{kt+1} - R_t)] \geq 0. \quad (29)$$

Under frictionless capital markets, (29) holds always with equality. In contrast, the discounted spread between the two rates is positive in the presence of financial frictions, as they limit the ability of financial intermediaries to obtain funds. Thus, given financial constraints, a bank has an incentive to invest all its funds and retain all earnings until the time it exits the business. The event of exit occurs with time-varying probability $1 - \theta_t$, where $\theta_t \equiv \theta \vartheta_t$, with ϑ_t being the disturbance to the banks' survival probability.¹² Upon exiting, a banker transfers its terminal wealth to the household and becomes a worker. Incorporating a finite horizon for financial intermediaries prevents them from accumulating enough net worth such that the financial constraint is no longer binding.¹³

¹²This shock can be interpreted as a net worth shock since it reduces the internal funds of the banking system. See, e.g., Afrin (2017) or Aoki and Sudo (2012). Since it also directly affect the stochastic marginal value of the net worth, I will refer to a negative realization of this shock as to a bank distress shock.

¹³By applying the law of large numbers, $f(1 - \theta_t)$ bankers exit the business in period t . They are replaced by workers who randomly become bankers. As a result, the size of each group remains constant over time.

Accordingly, financial intermediary j determines optimal asset holdings and the amount of external funds to maximize its franchise value, given by

$$V_{jt} = \max E_t \left[\sum_{k=1}^{\infty} \Lambda_{t,t+k} \left(\prod_{i=t+1}^{t+k-1} \theta_i \right) (1 - \theta_{t+k}) N_{jt+k} \right], \quad (30)$$

with $(\prod_{i=t+1}^t \theta_i) \equiv 1$.

Following Gertler and Karadi (2011), I introduce a moral hazard problem to motivate a limited ability of obtaining funds by financial intermediaries. In particular, at the beginning of each period, a banker can divert a non-bank specific fraction, λ , of her assets and transfers it to her household. In this situation, depositors can force her into bankruptcy and recover the remaining fraction of assets, $1 - \lambda$. Hence, households are willing to supply funds to the intermediary j only if the continuation value of its operations is greater (or equal) than the gain from diverting the assets, i.e.,

$$V_{jt} \geq \lambda Q_t K_t. \quad (31)$$

To solve the model, I first write (30) recursively

$$V_{jt} = \max E_t [\Lambda_{t,t+1} ((1 - \theta_{t+1}) N_{jt+1} + \theta_{t+1} V_{t+1})] \quad (32)$$

and conjecture that the solution is linear in the value of assets and deposits

$$\begin{aligned} V_{jt} &= v_t^k Q_t K_{jt} - v_t D_{jt} \\ &= \mu_t Q_t K_{jt} + v_t N_{jt}, \end{aligned} \quad (33)$$

where the second equality follows from the balance sheet condition. v_t^k is the marginal gain of holding assets, whereas v_t is the marginal cost of deposits and can be also inter-

puted as marginal value of net worth, holding the assets constant.¹⁴ Thus, $\mu_t \equiv v_t^k - v_t$ can be interpreted as the marginal gain of expanding assets by one unit financed via deposits.¹⁵ Then, the financial constraint can be written as

$$\mu_t Q_t K_{jt} + v_t N_{jt} \geq \lambda Q_t K_t. \quad (34)$$

Maximizing (33) subject to (34), under the assumption that the financial constraint always binds, yields the following conditions

$$\mu_t(1 + \psi_t) = \lambda \psi_t, \quad (35)$$

and

$$Q_t K_{jt} = \phi_t N_{jt}, \quad (36)$$

where ψ_t is the Lagrange multiplier on the incentive constraint. Furthermore, ϕ_t denotes the leverage ratio and is given by

$$\phi_t \equiv \frac{v_t}{\lambda - \mu_t}. \quad (37)$$

Note that holding the net worth constant, the constraint binds more tightly, when the intermediary can divert a higher fraction of assets, λ , and the excess value of bank assets is low. With low excess value, the franchise value of the intermediary is lower and the managing banker has a strong incentive to divert funds.

To determine expressions for shadow values of assets and deposits, i.e., time-varying coefficients in the value function, I insert the law of motion of net worth into the Bellman equation, (32), and verify that the initial guess for the value function is correct for

$$v_t^k = E_t [\Lambda_{t,t+1} \Omega_{t+1} R_{kt+1}], \quad (38)$$

¹⁴Given bank's asset holdings, an additional unit of net worth leads to savings in borrowing costs.

¹⁵Note that the marginal values are not bank specific. The underlying assumption is that there are no structural differences across financial intermediaries.

$$v_t = E_t [\Lambda_{t,t+1} \Omega_{t+1}] R_t, \quad (39)$$

and

$$\mu_t \equiv v_t^k - v_t = E_t [\Lambda_{t,t+1} \Omega_{t+1} (R_{k,t+1} - R_t)], \quad (40)$$

where Ω_{t+1} is the stochastic marginal value of net worth in period $t + 1$, defined in the following way

$$\Omega_{t+1} \equiv 1 - \theta_{t+1} + \theta_{t+1} (v_{t+1} + \phi_{t+1} \mu_{t+1}). \quad (41)$$

Due to the presence of financial frictions, bankers do not only care about the consumption fluctuations of their households (reflected by $\Lambda_{t,t+1}$) but they also consider their funding conditions (reflected by Ω_{t+1}).

Since the leverage ratio does not depend on bank specific factors (see 37), we can sum across all individual banks to obtain the aggregate leverage constraint

$$Q_t K_t = \phi_t N_t. \quad (42)$$

To obtain the law of motion for the net worth of the entire banking system, one has to recognize that it is the sum of net worth of surviving intermediaries, N_{ot} , and net worth of new bankers, N_{nt}

$$N_t = N_{ot} + N_{nt}. \quad (43)$$

As already discussed, a fraction $1 - \theta_t$ of financial intermediaries exit the market in period t and are replaced by workers who randomly become bankers. New bankers require a start-up capital to be able to attract funds from depositors. Similarly to Gertler and Karadi (2011), I assume that the household transfers a fraction, $\frac{\omega}{1-\theta_t}$, of the value of assets of exiting intermediaries. Hence,

$$N_{nt} = \omega Q_t K_{t-1}. \quad (44)$$

The net worth of the remaining θ_t bankers is given by

$$N_{ot} = \theta_t [(R_{kt} - R_{t-1}) \phi_{t-1} + R_{t-1}] N_{t-1}. \quad (45)$$

3.4 Aggregate Resource Constraint and Monetary Policy

Final output is divided between consumption and investment

$$Y_t = C_t + I_t + \frac{\eta}{2} \left(\frac{I_{nt} + \bar{I}}{I_{nt-1} + \bar{I}} - 1 \right)^2 (I_{nt} + \bar{I}). \quad (46)$$

The law of motion for capital is given by

$$K_t = \xi_t K_{t-1} + I_{nt}. \quad (47)$$

Following Gertler and Karadi (2011), I assume that the monetary policy is described by the following Taylor-rule

$$1 + i_t = (1 + i_{t-1})^{\rho_i} \left[(1 + i_{SS}) \Pi_t^{\kappa_\pi} \left(\frac{X_t}{\bar{X}} \right)^{\kappa_x} \right]^{1-\rho_i}, \quad (48)$$

where i_t denotes the net nominal interest rate with a deterministic steady state value of i_{SS} . $\rho_i \in (0, 1)$ is the smoothing parameter, and the parameters κ_π and κ_x capture the responsiveness of nominal interest rate to movements in inflation and markup. Markup fluctuations serve as a proxy for movements in the output gap, defined as a deviation of output under rigid prices from its flexible price counterpart.

Finally, the nominal interest rate affects the real economy via the Fisher equation

$$1 + i_t = R_t E_t [\Pi_{t+1}]. \quad (49)$$

3.5 Shock Processes

There are three first-moment shock processes present in the model: technology, A_t , capital quality, ξ_t , and a disturbance to the survival probability of financial intermediaries, ϑ_t :

$$A_t = (1 - \rho_A) + \rho_A A_{t-1} + e^{\bar{\sigma}^A} \epsilon_t^A, \quad (50)$$

$$\xi_t = (1 - \rho_\xi) + \rho_\xi \xi_{t-1} + e^{\bar{\sigma}^\xi} \epsilon_t^\xi, \quad (51)$$

and

$$\vartheta_t = (1 - \rho_\vartheta) + \rho_\vartheta \vartheta_{t-1} + e^{\sigma_{\vartheta}^\vartheta} \epsilon_t^\vartheta, \quad (52)$$

with ρ denoting the corresponding autocorrelation coefficient and σ being the standard deviation of the respective stochastic disturbance.

Financial uncertainty is introduced into the model by assuming that the volatility of shocks to the survival probability of bankers varies over time. The corresponding second-moment process is given by

$$\sigma_t^\vartheta = (1 - \rho_{\sigma^\vartheta}) \bar{\sigma}^\vartheta + \rho_{\sigma^\vartheta} \sigma_{t-1}^\vartheta + \tau_{\sigma^\vartheta} \epsilon_t^\vartheta, \quad (53)$$

where $\bar{\sigma}^\vartheta$ refers to the unconditional mean level of σ_t^ϑ , ρ_{σ^ϑ} is again the persistence parameter, and τ_{σ^ϑ} is the standard deviation of volatility innovations. The standard deviations of the remaining two level shocks are assumed to be constant in the baseline model.¹⁶

All innovations are independent and follow a symmetric distribution with bounded support, zero mean and unit variance. The first-moment processes are specified in levels, rather than logs to prevent changes in volatility from affecting their mean values through

¹⁶In section 5.3, I extend the model and discuss responses to stochastic volatility shocks associated with total factor productivity. The goal of this exercise is to detect differences in propagation mechanisms of different types of uncertainty disturbances. Moreover, it enables a comparison with the literature investigating the propagation of real uncertainty shocks under financial frictions (e.g., Bonciani and Van Roye (2016)).

a Jensen's inequality effect.

4 Solution Method and Calibration

Due to nonlinearities present in the model, an exact solution is not feasible and thus one must rely on approximation methods. This section describes the technique used to solve the model and discusses the calibration underlying the analysis conducted in this paper.

4.1 Perturbation Methods

As shown by Fernández-Villaverde et al. (2011), at least a third-order approximation is necessary to investigate impulse responses to volatility shocks. I use the nonlinear moving average perturbation developed by Lan and Meyer-Gohde (2013). This technique has two advantages in a setup with time-varying risk. First, it starts the approximation at the stochastic steady state.¹⁷ Second, it delivers stable nonlinear impulse responses and simulations and thus no ad-hoc pruning algorithm is necessary.

To explain the method, I will cast the underlying model into a general form

$$E_t [f(y_{t+1}, y_t, y_{t-1}, \epsilon_t)] = 0, \quad (54)$$

where $f : \mathbb{R}^{ny} \times \mathbb{R}^{ny} \times \mathbb{R}^{ny} \times \mathbb{R}^{ne} \rightarrow \mathbb{R}^{ny}$ is assumed to be analytic, $y_t \in \mathbb{R}^{ny}$ stands for the vector containing both endogenous and exogenous variables, and $\epsilon_t \in \mathbb{R}^{ne}$ is a vector of zero-mean iid shocks. The nonlinear moving average represents a solution to (54) as a direct mapping of the history of shocks to model variables, i.e.,

$$y_t = y(\sigma, \epsilon_t, \epsilon_{t-1}, ..), \quad (55)$$

¹⁷The stochastic or risky steady state is defined as a fixed point in the absence of past and present shocks but taking into account the likelihood of shocks in the future. See, e.g., Coeurdacier et al. (2011), Juillard (2011) and Meyer-Gohde (2014).

where σ is the perturbation parameter, governing the size of risk in the model. $\sigma = 0$ implies a deterministic setup, whereas $\sigma = 1$ refers to the fully stochastic world. The third-order Taylor approximation of this policy function, given a symmetric distribution of shocks and $\sigma = 1$, is given by

$$\begin{aligned}
y_t^{(3)} = & y_{SS} + \frac{1}{2}y_{\sigma^2} + \sum_{i=0}^{\infty} \left(y_i + \frac{1}{2}y_{\sigma^2 i} \right) \epsilon_{t-i} + \frac{1}{2} \sum_{i_1=0}^{\infty} \sum_{i_2=0}^{\infty} y_{i_1, i_2} (\epsilon_{t-i_1} \otimes \epsilon_{t-i_2}) \\
& + \frac{1}{6} \sum_{i_1=0}^{\infty} \sum_{i_2=0}^{\infty} \sum_{i_3=0}^{\infty} y_{i_1, i_2, i_3} (\epsilon_{t-i_1} \otimes \epsilon_{t-i_2} \otimes \epsilon_{t-i_3}),
\end{aligned} \tag{56}$$

where y_{SS} denotes the deterministic steady state of the model and y_i , y_{i_1, i_2} , y_{i_1, i_2, i_3} , y_{σ^2} , $y_{\sigma^2, i}$ refer to partial derivatives of the policy function evaluated at the deterministic steady state. The expression $y_{SS} + \frac{1}{2}y_{\sigma^2}$ corresponds to the third-order accurate stochastic steady state.¹⁸ Moreover, $y_{\sigma^2, i}$ adjusts the approximate responses of endogenous variables to shock realizations for the risk of future disturbances.

4.2 Calibration

Table 1 reports the benchmark calibration. For all parameters I choose values previously used in the literature, with Gertler and Karadi (2011) being the major source.

The inverse of the Frish elasticity of labor supply, φ , is set to 0.276, whereas parameter governing habit formation, h , is 0.815. The choice of the value for χ ensures that labor supply in the deterministic steady state equals 0.33.

The capital share, α , in production is 0.33. The elasticity of marginal depreciation with respect to the utilization rate, δ_2 , is set to 7.2. The remaining parameters of the depreciation function, δ_0 and δ_1 , are chosen such that the depreciation rate and the utilization of capital are equal respectively to 0.025 and 1 in the deterministic steady state. Following Born and Pfeifer (2014) I set the elasticity of substitution between intermediate goods, ϱ ,

¹⁸As shown by Andreasen (2012), the third-order constant term, y_{σ^3} , corrects the approximation for the skewness of the shocks. Since I assume symmetric distributions, it is equal to zero and thus omitted from (56).

Parameter		Value	Justification
Household			
Discount factor	β	0.99	Gertler Karadi (2011)
Habit parameter	h	0.815	Gertler Karadi (2011)
Inverse of intertemporal elasticity of substitution	γ	1	Gertler Karadi (2011)
Inv. Frish elasticity of labor supply	φ	0.276	Gertler Karadi (2011)
Relative utility weight of labor	χ	3.1870	$L_{SS} = \frac{1}{3}$
Nonfinancial Firms			
Effective capital share	α	0.33	Gertler Karadi (2011)
Inv. elasticity of invest. to the price of capital	η	1.5	Gertler Kiyotaki (2010)
Elasticity of marginal depreciation w.r.t. U_t	δ_2	7.2	Gertler Karadi (2011)
Depreciation rate parameter 1	δ_1	0.0376	$U_{SS} = 1$
Depreciation rate parameter 2	δ_0	0.0204	$\delta_{SS} = 0.025$
Elasticity of substitution	ϱ	10	Born Pfeifer (2014)
Calvo parameter	θ_{calvo}	0.779	Gertler Karadi (2011)
Financial Sector			
Survival rate of bankers	θ	0.967	
Divertable fraction	λ	0.3556	
Starting-up transfer	ω	0.0034	
Taylor Rule			
Interest Rate Smoothing Parameter	ρ_i	0.8	Gertler Karadi (2011)
Inflation coefficient in Taylor rule	κ_π	1.5	Gertler Karadi (2011)
Output coefficient in Taylor rule	κ_x	-0.125	Gertler Karadi (2011)
Shock Processes			
Persistence - TFP	ρ_A	0.95	Gertler Karadi (2011)
Persistence - Capital quality	ρ_ξ	0.66	Gertler Karadi (2011)
Persistence - Survival probability	ρ_θ	0.85	Afrin (2016)
Persistence - Stochastic volatility	ρ_{σ^θ}	0.9	Estimated
Unconditional mean of log-S.D.	$\bar{\sigma}^i$	$\ln(0.01)$	
S.D. - Stochastic volatility	τ_{σ^θ}	0.045	Estimated

Table 1: Calibration

to 10, implying a markup of 11 % in the deterministic steady state. Moreover, the price rigidity parameter, θ_{calvo} , takes the value of 0.779, resulting in an average lifetime of a price of four and a half quarters.

θ is set to 0.967 implying an average horizon of bankers of almost eight years. Following Gertler and Karadi (2011), λ and ω are chosen to target the following two targets: an interest rate spread of one hundred basis points per year and banks' leverage ratio of four in the deterministic steady state.

The autocorrelation parameters of the level shocks are set in accordance with Gertler and Karadi (2011) and Afrin (2017). Moreover, the unconditional mean of their respective standard-deviations is equal to 0.01.¹⁹ To parametrize the second-moment process for the survival probability of bankers, I assume, in accordance with Ludvigson et al. (2015), that fluctuations in financial uncertainty are exogenous. Given this assumption, the financial uncertainty measure corresponds directly to the stochastic volatility process (53). To see this, consider the error associated with the one-step-ahead forecast of θ :

$$U_\theta \equiv \sqrt{E_t \left[(\theta_{t+1} - E_t [\theta_{t+1}])^2 \right]} = e^{\sigma_t^\theta} \quad (57)$$

Taking the natural logarithm of (57) yields

$$\ln(U_\theta) = \sigma_t^\theta. \quad (58)$$

Therefore, I can use the financial uncertainty series to directly estimate the parameters of the stochastic volatility process for the survival probability of banks. The estimated autocorrelation parameter is 0.9, whereas the implied standard deviation is 0.045.²⁰

¹⁹Gertler and Karadi (2011) assume a standard deviation of 0.05 for the capital quality shock. Note, however, that they require a higher value to construct a crisis situation.

²⁰These values are consistent with the estimates of Richter and Throckmorton (2018).

5 Results

In this section, I trace out aggregate effects of financial uncertainty shocks in the underlying framework. Then, I conduct sensitivity analysis by modifying the calibration in several ways to assess the importance of individual features of the model. Finally, I discuss differences in transmission mechanisms of financial and macroeconomic uncertainty. To this end, I introduce time-varying volatility of the total factor productivity shock serving as a proxy for macroeconomic uncertainty.

5.1 Financial Uncertainty Shocks

Figure 2 depicts the response of the model economy to one standard deviation increase in the financial uncertainty shock. The responses represent third-order accurate (percentage) deviations of model variables from their respective stochastic steady states. An adverse financial uncertainty shock implies an increase in the expected stochastic marginal value of net worth in the subsequent period. This leads to a rise in the shadow costs of deposits today, which in turn reduces the franchise value of intermediaries and thus reduces households' demand for riskless bonds, i.e., deposits. As a consequence, the real return on deposits increases. Simultaneously, current consumption declines given that expected future consumption affects today's marginal utility via the internal habit formation. Tighter funding conditions force the banks to reduce their lending and as a consequence investment falls. Lower investment leads to a reduction in the price of capital which deteriorates the financial position of banks even further (*financial accelerator*). In particular, a lower price of capital translates into a lower rate of return on bank investment and net worth of the banking system diminishes. In addition, because of higher uncertainty retailers raise their markups (see Born and Pfeifer, 2014 and Born and Pfeifer, 2017). This precautionary pricing behavior contributes to the decline in the aggregate demand. The price of the intermediate goods, i.e., marginal costs of

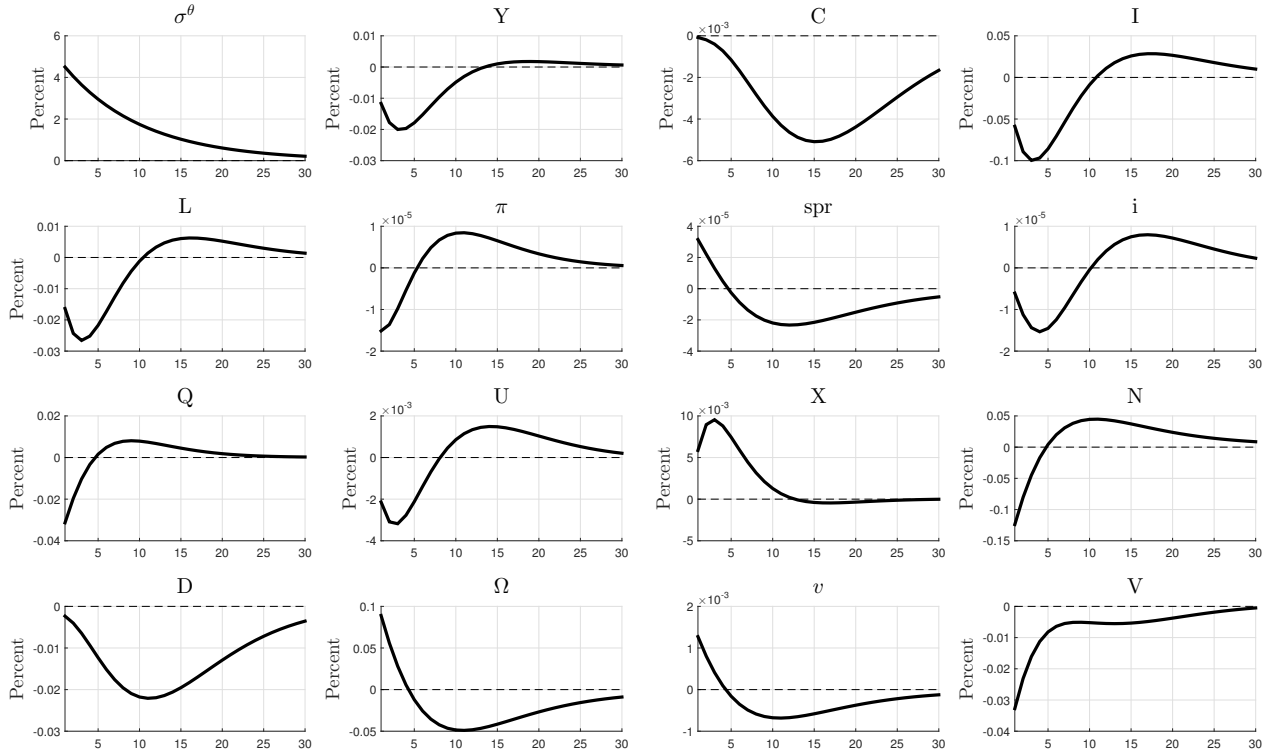


Figure 2: Dynamic consequences of financial uncertainty shocks. *Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i), the shadow price of deposits (v) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

retailers, falls and thus the inflation rate drops despite the higher average markup. Finally, falling aggregate demand for goods implies a reduction of hours worked and a drop in the production level. The peak response of output occurs after three quarters and amounts to a drop of about 0.02 % of production in the stochastic steady state. The subsequent recovery is followed by a rebound which is caused by the fact that the capital stock needs to be replenished when the shock dies out. Therefore, the model can generate the *volatility overshoot* that can be found in the data. Finally, note that the model has difficulty with replicating the magnitude of the dynamic responses to financial second-

moment shocks.²¹ More importantly, however, the theoretical impulse responses are qualitatively consistent with their empirical counterparts.

5.2 Dissecting the Transmission Channels of Financial Uncertainty

This section assesses the importance of different model features for the transmission mechanism of financial uncertainty. In particular, I discuss the role of nominal rigidities, internal habit formation and variable capital utilization.

5.2.1 Nominal Rigidity

Price rigidity affects the transmission of uncertainty shocks via the clearing condition for the labor market (Basu and Bundick, 2017; Born and Pfeifer, 2014; Born and Pfeifer, 2017):

$$\frac{1}{X_t} A_t (1 - \alpha) (\xi_t K_{t-1})^\alpha U_{Ct} = \chi L_t^{\varphi+\alpha}. \quad (59)$$

In particular, a rise in volatility results in an increase of the markup which in turn diminishes the demand for goods and consequently output as well as labor demand.

As explained by Born and Pfeifer (2017), the rise in markup following an uncertainty shock is caused by the precautionary pricing behavior of retailers. In particular, a firm, updating its price in a more uncertain environment, has an incentive to charge a higher markup because higher prices partly compensate for a low quantity sold. On the other hand, lower prices imply a higher demand but the revenue per unit sold is lower. This diminishes retailers' profits. Because of the nonlinear nature of the pricing behavior, firms prefer higher prices.

Figure 3 compares the impulse responses to a financial uncertainty shock under

²¹The underlying framework can be modified along several dimensions to improve its quantitative implications. Possible extensions are sticky wages (Born and Pfeifer, 2017) and monopolistic power in the banking sector (Bonciani and Van Roye, 2016). This paper abstracts from these features to isolate the core propagation mechanism and focuses on qualitative characteristics of the dynamic consequences of financial uncertainty fluctuations.

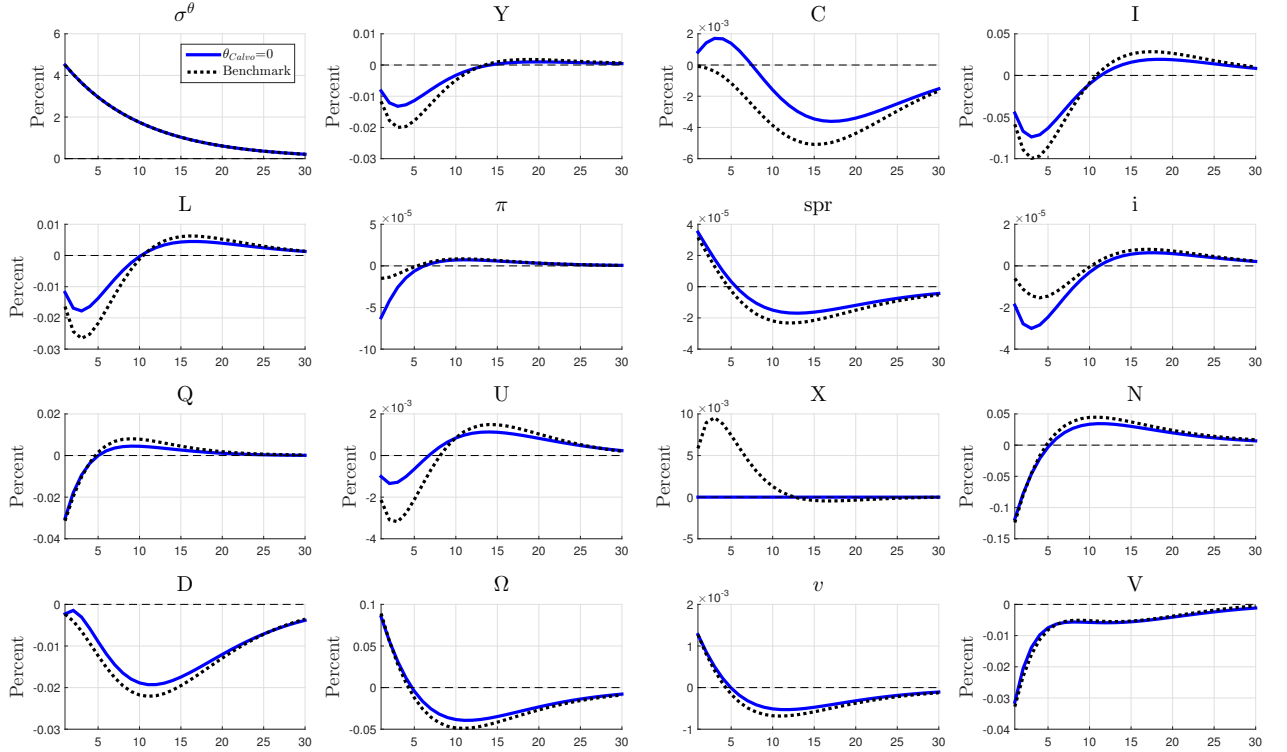


Figure 3: Assessing the importance of nominal rigidities. *Dynamic consequences of a one-standard-deviation increase in the volatility of shocks to the survival probability of banks. Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i), the shadow price of deposits (v) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

the benchmark calibration with their counterparts under flexible prices. The precautionary pricing motive amplifies the effects of an increase in the volatility of shocks to the survival probability of bankers. In addition, similar to the model employed by Basu and Bundick (2017), nominal rigidity is necessary to replicate empirically observed co-movement among aggregate quantities in the underlying framework. The next section shows, however, that sticky prices alone are not sufficient to generate this outcome. They have to be accompanied by the internal habit formation.

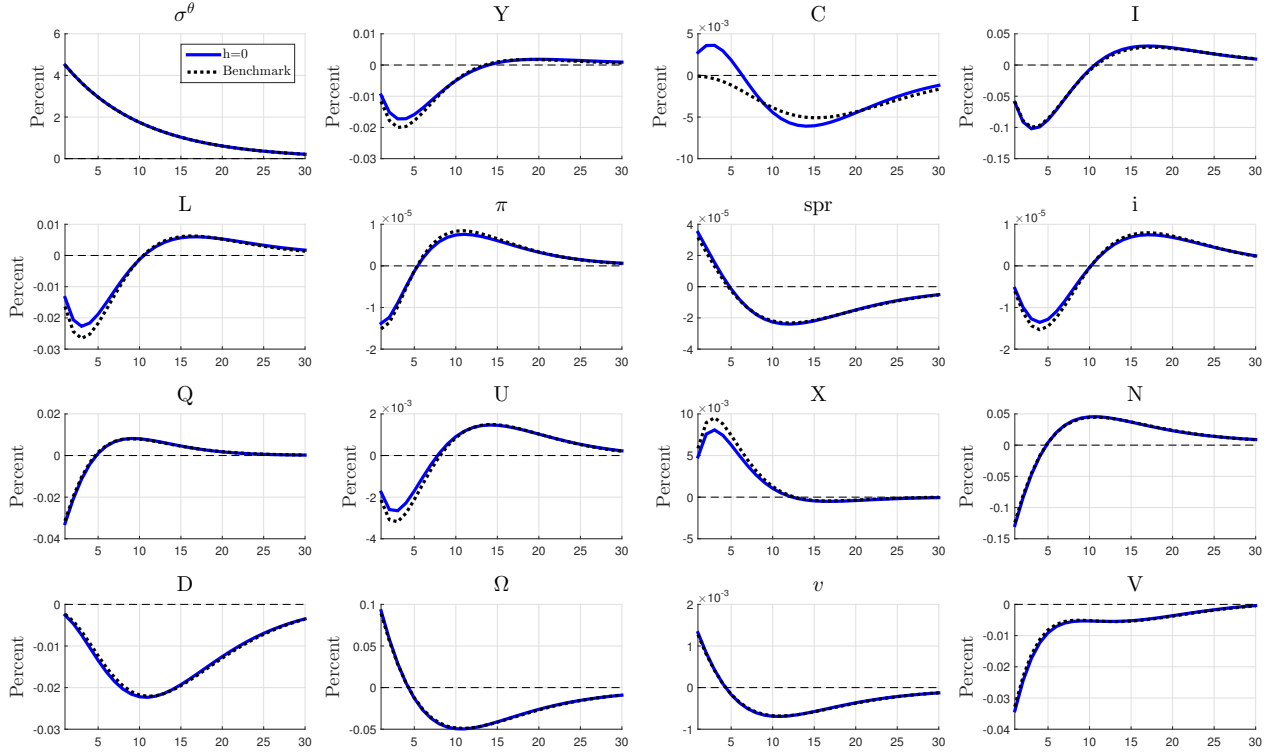


Figure 4: Assessing the importance of internal habit formation. *Dynamic consequences of a one-standard-deviation increase in the volatility of shocks to the survival probability of banks. Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i), the shadow price of deposits (v) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

5.2.2 Internal Habit Formation

To quantify the importance of habit formation, I remove this feature by setting $h = 0$ and compare the implied model responses to the benchmark calibration. Figure 4 presents the results of this exercise. Without habit formation, the macroeconomic effects of an adverse uncertainty shock are weaker. More importantly, however, the model can no longer generate the co-movement among the macroeconomic aggregates. To understand this outcome, note that internal habit formation implies that the marginal utility of consumption today depends on the expected future consumption stream, i.e.,

$U_{Ct} = (C_t - hC_{t-1})^{-\gamma} - \beta h E_t [(C_{t+1} - hC_t)^{-\gamma}]$. As shown by figure 4, consumption has to fall eventually due to lower production, even if h is set to zero. Hence, under internal habit formation, the household internalizes the habitual nature of consumption and starts reducing its stock of habit already in $t = 0$ to avoid large jumps in its marginal utility. Furthermore, note that a rise in uncertainty depresses, *ceteris paribus*, the marginal utility of today's consumption via the Jensen's inequality. Therefore, the household has an incentive to reduce its labor supply, as it derives less utility from a given wage. The implied reduction in hours worked is consistent with lower aggregate demand in the New Keynesian setup.

In contrast, without internal habit formation, the household simply consumes additional resources that become available due to the reduction in bank deposits. Thus, the aggregate consumption rises on impact despite a drop in the production level. As a result, the negative effect of the financial uncertainty shock on the aggregate activity is smaller.

Why are both sticky prices and internal habit formation necessary to generate a drop in consumption in response to an adverse financial uncertainty shock? A rise in financial uncertainty is transmitted to the real economy via tighter financial conditions. The resulting drop in deposits stimulates consumption, *ceteris paribus*. To prevent an increase of aggregate consumption, production level must fall sufficiently strongly (due to higher markups) and households must strongly dislike consumption fluctuations.²²

The role of internal habit formation as a propagator of (macro) uncertainty has been documented by Leduc and Liu (2016). The authors show that in a framework with search frictions in the labor market, internal habit formation amplifies the effects of uncertainty shocks on unemployment because it induces a larger drop in the present value of a job match. This finding stands in contrast to the results of Born and Pfeifer (2014) who em-

²²In contrast, internal habit formation is not necessary to generate a drop in consumption in case of macroeconomic uncertainty modeled by the stochastic volatility of the total factor productivity. The reason is that the presence of financial frictions only amplifies the impact of macroeconomic uncertainty shocks and is not crucial for them to affect the real economy.

ploy a New Keynesian model without search and financial frictions. In their framework, habit formation dampens the effects of uncertainty because adjustment in consumption is more costly in terms of utility. My results are in line with Leduc and Liu (2016) and confirm that internal habit formation can amplify uncertainty shocks in presence of other frictions. In the underlying framework, this additional friction is the agency problem in the financial sector. In other words, endogenous leverage constraint is (indirectly) an important model feature for generating a decline in the consumption in response to an increase in financial uncertainty.

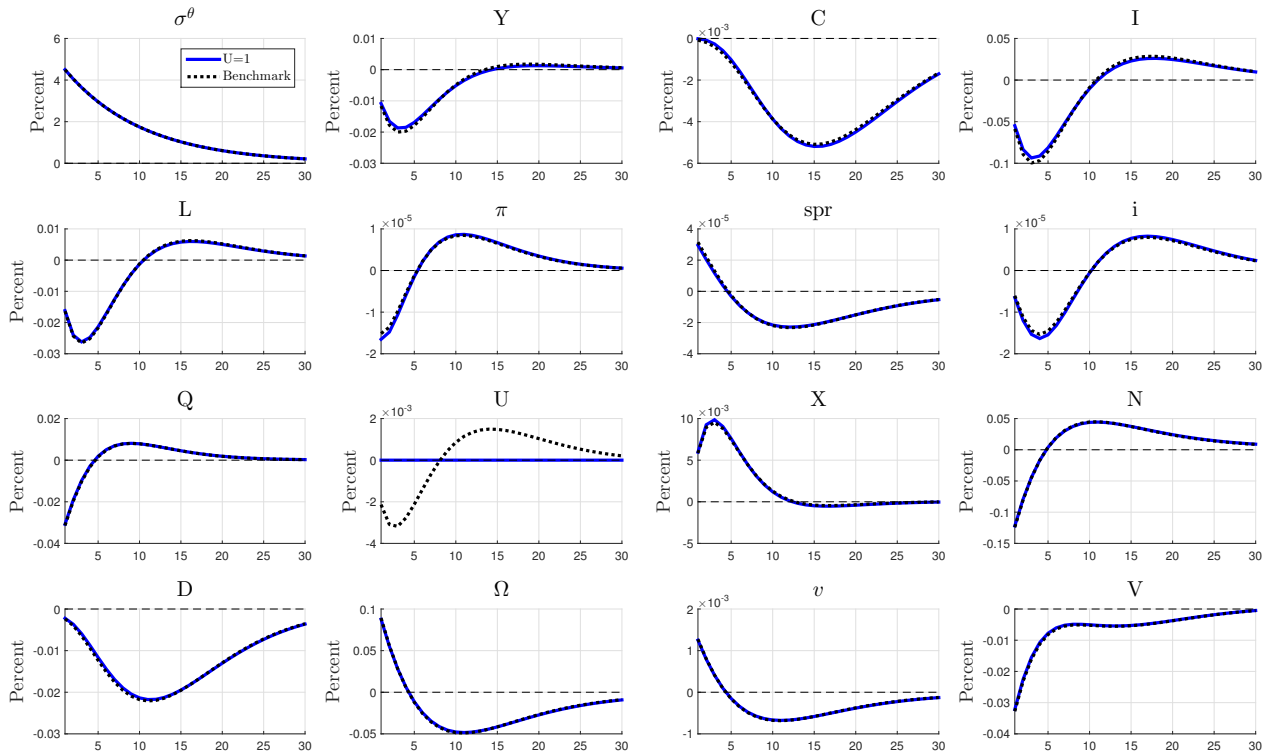


Figure 5: Assessing the importance of variable capital utilization. *Dynamic consequences of a one-standard-deviation increase in the volatility of shocks to the survival probability of banks. Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i), the shadow price of deposits (v) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

5.2.3 Variable Capital Utilization

To assess the importance of variable capital utilization, I compare the baseline framework with the model, where capital utilization is fixed at its deterministic steady state level, i.e., $U_t = 1 \quad \forall t$. Figure (5) presents the results of this exercise. The effects of financial uncertainty shocks are stronger if we allow for variable capital utilization. To understand this outcome, consider equation (11) which, using the specification of the depreciation function, can be rewritten as

$$\alpha \frac{1}{X_t} A_t \left(\frac{L_t}{\xi_t K_{t-1}} \right)^{1-\alpha} = \delta_1 U_t^{\delta_2 + 1 - \alpha}. \quad (60)$$

An adverse financial uncertainty shock implies a higher economy-wide markup and lower labor supply, which in turn, depresses the marginal product of capital utilization, as reflected by a lower right-hand side of (60). Firms' optimal response is to lower the capital utilization to reduce the (marginal) depreciation of capital. Finally, lower U_t reduces income and, thereby, depresses the aggregate demand, which ultimately leads to a stronger drop in production. Note, however, that the amplification effect of variable capital utilization is small. With fixed capital utilization, the peak response of GDP amounts to a drop of 0.018% of the stochastic steady state production rather than 0.02 % realized in the benchmark model.

5.3 Comparison with Macroeconomic Uncertainty

In this section, I extend the model by introducing time-varying volatility of the total factor productivity shock which serves as a proxy for the macroeconomic uncertainty. For the sake of comparison, I calibrate the corresponding second-moment process by choosing the same parameter values as in the case of financial uncertainty. Another reason for following this calibration strategy is the fact that the literature provides mixed evidence on whether fluctuations in macroeconomic uncertainty represent exogenous

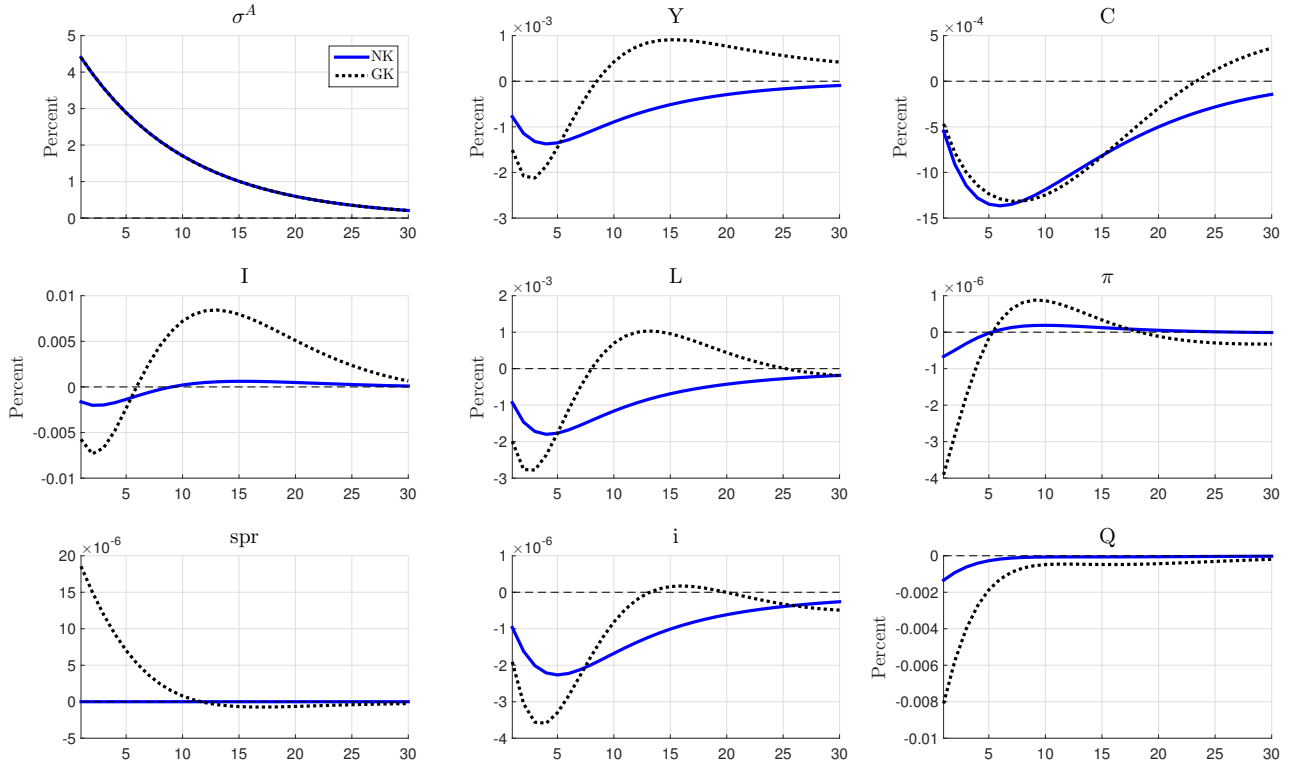


Figure 6: Dynamic consequences of macroeconomic uncertainty. *Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

shocks or an endogenous response to fundamentals. In particular, Ludvigson et al. (2015) provide evidence that movements in macro uncertainty are rather a consequence of changes in fundamentals and financial uncertainty. On the other hand, Caldara et al. (2016), exploiting different identification strategy, find that uncertainty regarding real variables has significant effects on the economic activity.

Figure 6 depicts the response of the model economy to an adverse realization of the macroeconomic uncertainty shock and compares it to its counterpart in a framework without financial frictions.²³ First, the dynamic consequences of macroeconomic

²³Note that I cannot repeat this exercise for financial uncertainty shocks, as financial uncertainty has no effects in the absence of financial frictions.

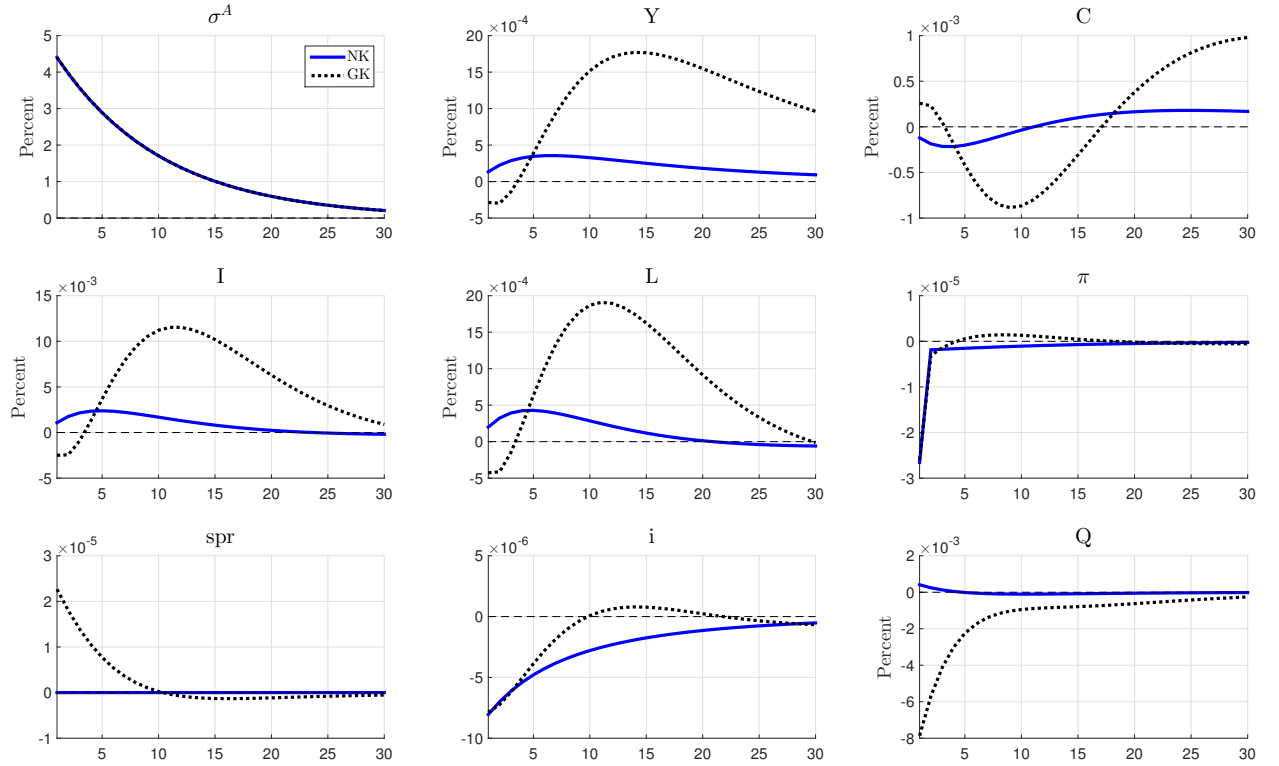


Figure 7: Dynamic consequences of macroeconomic uncertainty in the absence of nominal rigidities, habit formation and variable capital utilization. *Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation (π), the nominal interest rate (i) and the risk premium (spr), defined as the expected future rate of return on bank assets relative to the rate on deposits.*

and financial uncertainty share common qualitative characteristics. Second, similar to the models used by Alfaro et al. (2017) and Bonciani and Van Roye (2016), the Gertler-Karadi framework employed in this study exhibits the “finance-uncertainty multiplier”. Note, however, that the effects of macroeconomic uncertainty are amplified only in the first year and the economy recovers much faster, compared to the New Keynesian model without financial intermediaries.²⁴ The reason for this fast recovery is a quick accumulation of the net worth of the banking sector combined with cheap investment goods.

²⁴ This outcome is consistent with the results of Gertler and Karadi (2011) for the technology level shock.

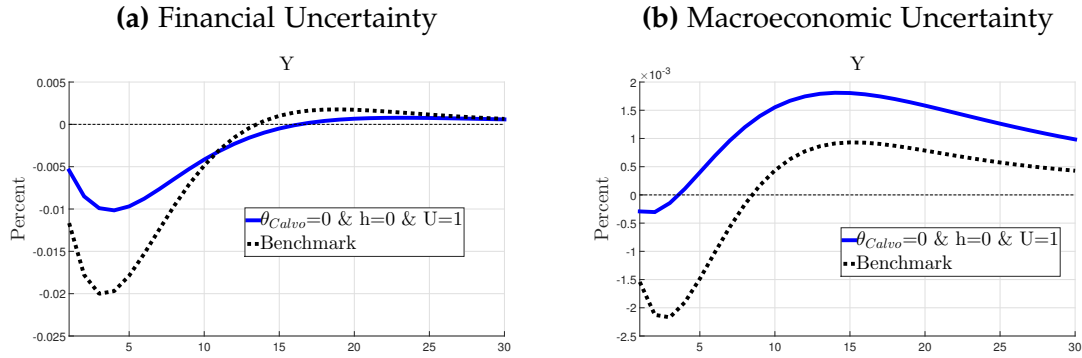


Figure 8: Macroeconomic versus Financial Uncertainty. *Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent.*

Figure 7 assesses the role of nominal rigidities, internal habit formation and variable capital utilization for the transmission mechanism of macroeconomic uncertainty. If these features are eliminated from the model, the negative effect of macroeconomic uncertainty becomes much smaller and short-lived. The GDP recovers already after one year and the economy experiences a persistent boom. The initial drop in the production is caused by the tightening of the financial constraint which prevents households from making deposits at banks. In the absence of financial frictions, a rise in macroeconomic uncertainty stimulates precautionary saving (Carroll and Kimball, 2006) and thereby generates an immediate increase in the production level.

Finally, figure 8 compares the importance of nominal rigidities, internal habit formation and variable capital utilization for dynamic consequences of financial and macroeconomic uncertainty. First, note that, even in the presence of these features, economic fluctuations caused by a second-moment TFP shock are less pronounced, compared to the effects of financial uncertainty. In particular, the peak drop in GDP under macroeconomic uncertainty is ten times smaller. Second, in contrast to financial uncertainty, shocks to the volatility of technology disturbances are propagated mainly through nominal and real rigidities. If they are eliminated from the model, the peak drop of GDP in response to the macroeconomic uncertainty shock is reduced by roughly 85 %. In contrast, the peak effect of financial uncertainty is smaller by 50 %.

6 Conclusion

This paper fills the gap in the DSGE literature on uncertainty shocks by shedding more light on the macroeconomic effects of financial uncertainty. The goal is to determine the channels through which financial uncertainty shocks are propagated to the real economy. To this end, I provide empirical evidence that financial uncertainty has significant impact on the real activity. To explain the empirical findings, I extend the DSGE framework developed by Gertler and Karadi (2011) by introducing time-varying volatility of financial shocks. The dynamics generated by the model are in line with their empirical counterparts. In particular, a rise in financial uncertainty leads to an increase in the risk premium and to a reduction in aggregate quantities. Finally, I conduct a series of experiments to uncover the main propagators of financial uncertainty. In the underlying setup, the key role is played by the endogenous leverage constraint faced by the bankers. Specifically, due to an increase in financial uncertainty, households provide less funding to financial intermediaries triggering the financial accelerator mechanism. Finally, nominal rigidities and internal habit formation act as additional amplification mechanisms for financial uncertainty shocks and, more importantly, are necessary to generate co-movement among macroeconomic aggregates.

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Appendix

A. Data Sources

I use the following data sources to estimate my VAR model. The data is available on the Federal Reserve Economic Database (FRED) unless specified otherwise:

1. **Financial Uncertainty Measure** - Monthly – Source: Ludvigson et al. (2015) – Data available from: <https://www.sydneyludvigson.com/data-and-appendixes/>
2. **Macro Uncertainty Measure** – Monthly – Source: Jurado et al. (2015) – Data available from: <https://www.sydneyludvigson.com/data-and-appendixes/>
3. **Nominal GDP** – Quarterly, Billions of Dollars, Seasonally Adjusted – FRED Code: GDP
4. **Personal Consumption Expenditures, Nondurable Goods** - Quarterly, Billions of Dollars, Seasonally Adjusted – FRED Code: PCND
5. **Personal Consumption Expenditures, Services** – Quarterly, Billions of Dollars, Seasonally Adjusted – FRED Code: PCESV
6. **Nominal Gross Private Investment** – Quarterly, Billions of Dollars, Seasonally Adjusted – FRED Code: GPDI
7. **Nonfarm Business Sector: Hours of all Persons** – Quarterly, Index 2009=100, Seasonally Adjusted – FRED Code: HOANBS
8. **GDP: Implicit Price Deflator** – Quarterly, Index 2009=100, Seasonally Adjusted – FRED Code: GDPDEF
9. **Moody's Seasoned Baa Corporate Bond Yield Relative to Yield on 10-Year Treasury Constant Maturity** – Monthly, Percent – FRED Code: BAA10YM

10. **Effective Federal Funds Rate** – Monthly, Percent – FRED Code: FEDFUNDS

11. **Civilian Noninstitutional Population** – Monthly, Thousands of Persons – FRED Code: CNP16OV

12. **Cboe S&P 100 Volatility Index - VXO** – Daily, Index – FRED Code: VXOCLS

All variables reported at a monthly or daily frequency are converted to a quarterly frequency by applying time averages. All nominal variables are converted to real terms by applying the GDP deflator. Finally, I express aggregate quantities in per-capita terms by dividing them by the civilian noninstitutional population.

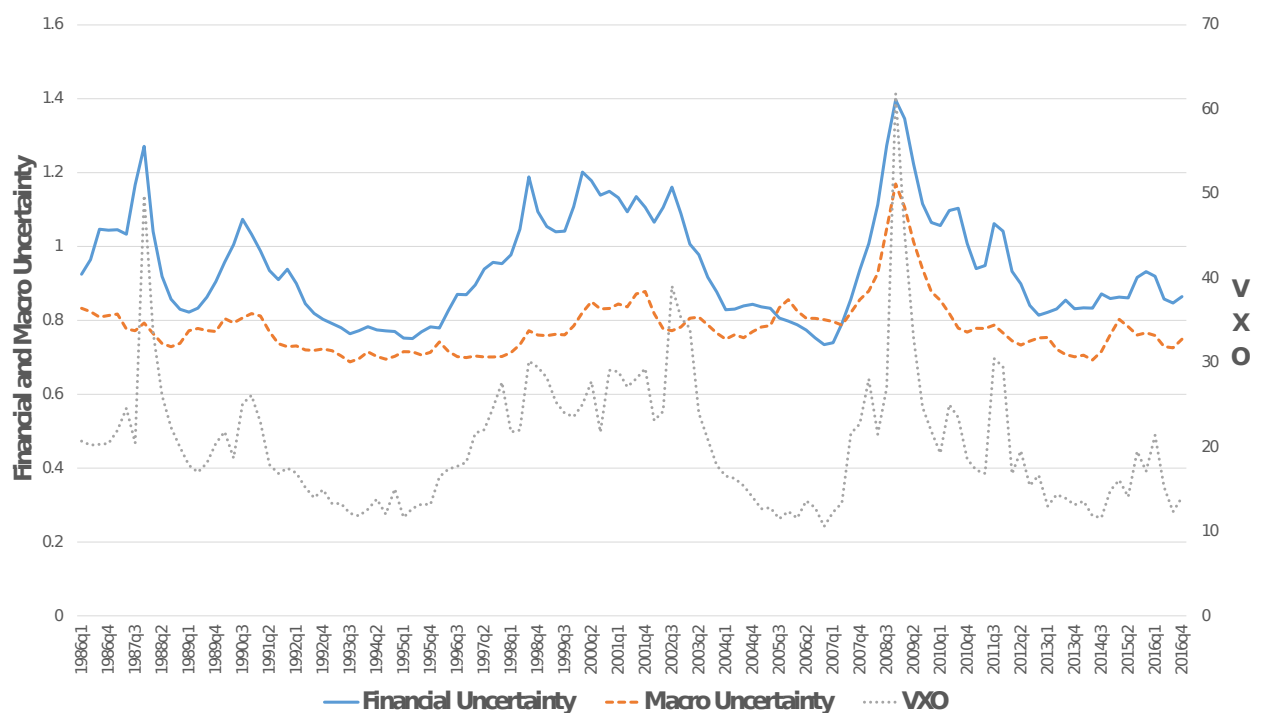


Figure 9: Measures of Uncertainty

B. Robustness of the VAR Results

Different ordering of the variables

To assess the robustness of the VAR evidence, I firstly use a different ordering of variables with the measure of financial uncertainty ordered last. This identification scheme allows the macroeconomic variables to contemporaneously affect financial uncertainty. Note that it is not consistent with my theoretical model. Moreover, it is also not supported by findings of Ludvigson et al. (2015). However, by employing this alternative ordering, I can show that the empirical evidence provided in this paper does not rely solely on the baseline identification strategy (see figure 10).

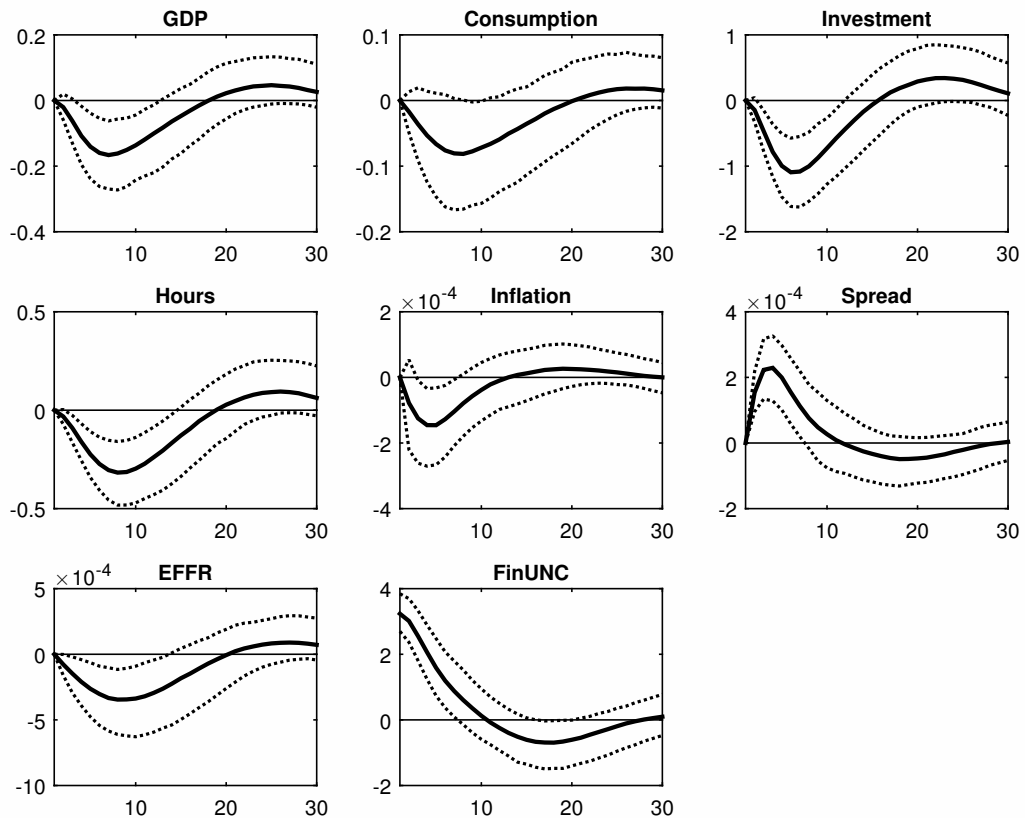


Figure 10: Dynamic consequences of one-standard-deviation increase in financial uncertainty. Horizontal axes indicate quarters. The solid curve denotes the median response, whereas the dotted curves refer to the 95 % confidence interval. Responses of all variables except inflation, the risk premium and the federal funds rate are in percent.

VXO as a measure of uncertainty

Following Caldara et al. (2016), I use the VXO as a proxy for financial uncertainty. This measure corresponds to the option-implied volatility and can thereby be related to financial markets. However, it may be capturing factors unrelated to movements in financial uncertainty, e.g., changes in risk aversion of investors. In the following, I estimate a VAR model with VXO ordered first.

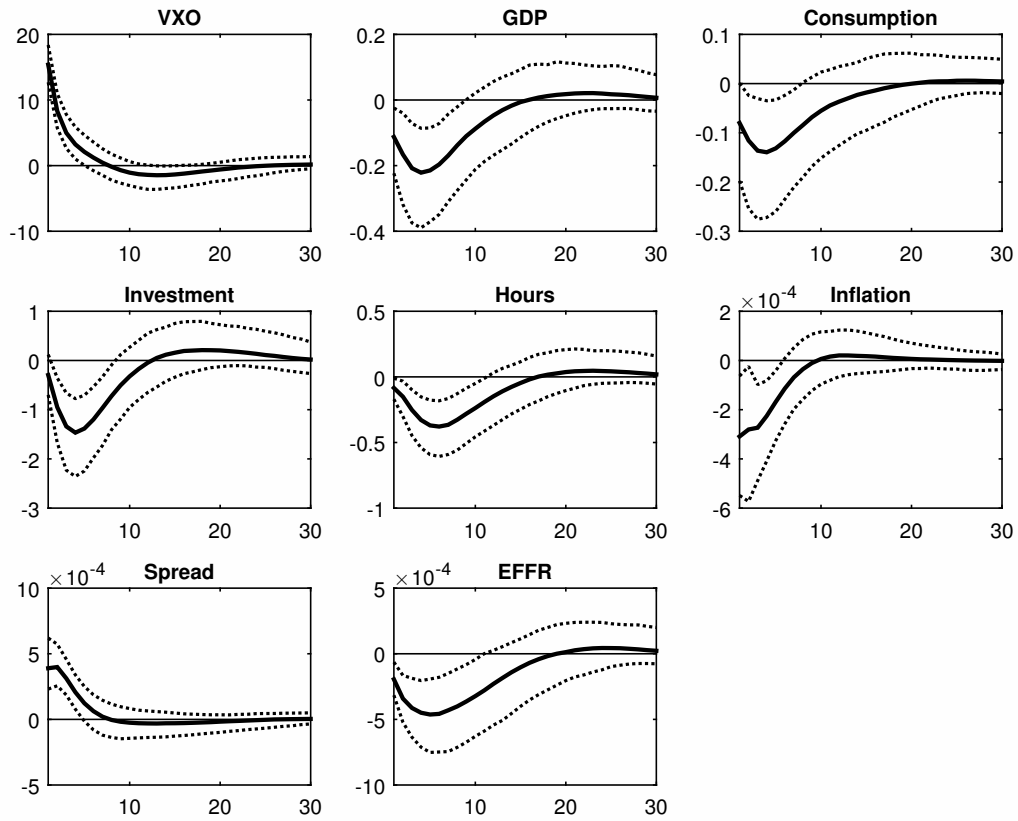


Figure 11: Dynamic consequences of one-standard-deviation increase in the VXO. Horizontal axes indicate quarters. The solid curve denotes the median response, whereas the dotted curves refer to the 95 % confidence interval. Responses of all variables except inflation, the risk premium and the federal funds rate are in percent.

Including a measure of macroeconomic uncertainty

Finally, I extend the set of variables used in the estimation exercise by including a measure of macroeconomic uncertainty constructed by Jurado et al. (2015). Given findings of Ludvigson et al. (2015), the measure of financial uncertainty is ordered first and is followed by the proxy for macro uncertainty and the remaining macroeconomic variables.

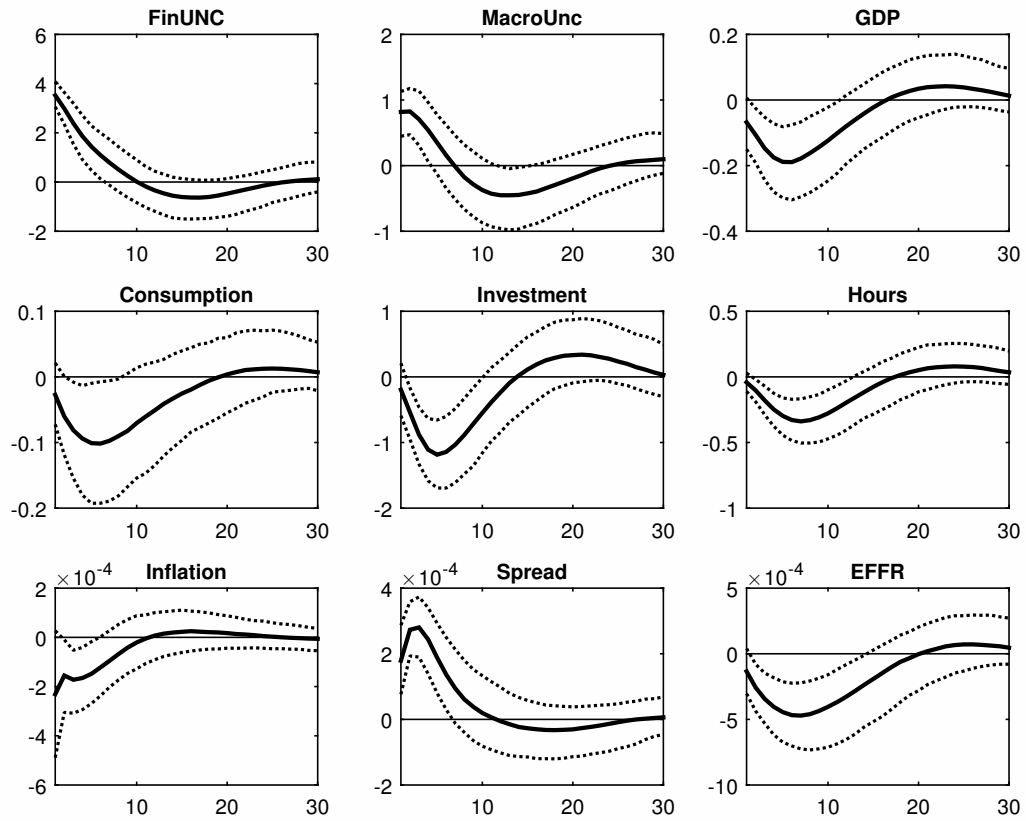


Figure 12: Dynamic consequences of one-standard-deviation increase in financial uncertainty. Horizontal axes indicate quarters. The solid curve denotes the median response, whereas the dotted curves refer to the 95 % confidence interval. Responses of all variables except inflation, the risk premium and the federal funds rate are in percent.