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Abstract

This thesis is composed of two self-contained chapters on macroeconomic impact of volatility shocks. Recently, there has been a surge in work on this subject which seeks to identify and establish how second-moment shocks can lead to sizable economic impact. In chapter 1 which is jointly written with Edgar Silgado-Gómez, we explore whether volatility shocks to spreads on bonds issued by peripheral eurozone economies of Spain, Ireland, Portugal and Italy was responsible for decline observed in these economies during the height of eurozone debt crisis and if it played a role in subsequent economic slowdown in these countries. Using SVAR-SV techniques, we are able to show that volatility shocks indeed had significant negative economic impact. In our study, a volatility shocks to the spread on sovereign bond is followed by a decline in bank net worth which precipitates a decline in banks' credit activities. As a lot of economic activity is dependent or at least supported by bank financing, these economic activities witness a fall. To explain the results we obtain from data. we use a medium size DSGE model augmented with a banking sector where banks hold government bonds and where the spreads on these bonds are subject to stochastically evolving second moment shocks. Consistent with what we see in our SVAR-SV analysis, a volatility shocks is followed by a drop in bank net worth and a reduction in its lending activity. This is then followed by a decline in investment, employment, output and consumption. Our findings underline the role that second moment shocks can play in affecting macroeconomic variables.

In chapter 2, I show that financial frictions amplify and compound the effects of fiscal volatility shocks. Using a calibrated DSGE model where firms are constrained by the amount of capital they can raise to support their production, I demonstrate that negative impact of fiscal volatility shocks are a lot worse than they are without it. The key mechanism explaining our results is a higher surge in firm markup when financial frictions are present than in their absence. These results highlight the role of unhindered access to finance for supporting economic activities – more so during the times where the economy is buffeted by more or larger than usual fiscal volatility shocks.

DISCLAIMER

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Contents

Chapter 1

Sovereign Spread Volatility and Banking Sector

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Abstract

Using structural vector autoregression augmented with stochastic volatility (SVAR-SV), we document that in late 2000s there were large spikes in volatility of spreads on peripheral eurozone government bonds. This increased volatility entailed a significant decline in bank credit to non-financial sector and real economic activity. We rationalize these results in a New Keynesian dynamic stochastic general equilibrium (DSGE) model with financial intermediation. In our framework, a rise in spread volatility erodes banks' net worth and constrains their balance sheets. The banks respond by slashing their lending to real sector, dampening the economy as a whole. Results from the model match our empirical findings.

1.1 Introduction

Shortly after the start of global financial crisis in 2008, the spreads on sovereign debt of many eurozone economies began climbing up and peaked during eurozone debt crisis of 2012 (see Figure 1.1). To put things into perspective, the spread on Spanish bonds during the height of eurozone debt crisis was 4.65 which was more than 77 times its mean value of 0.06 (average over 2000-2011). Similar trends were observed in other peripheral eurozone countries too such as Ireland, Portugal and Italy.[1]

[1]Sovereign spread is defined as return on one year Spanish government bonds net return on one year German government bonds.

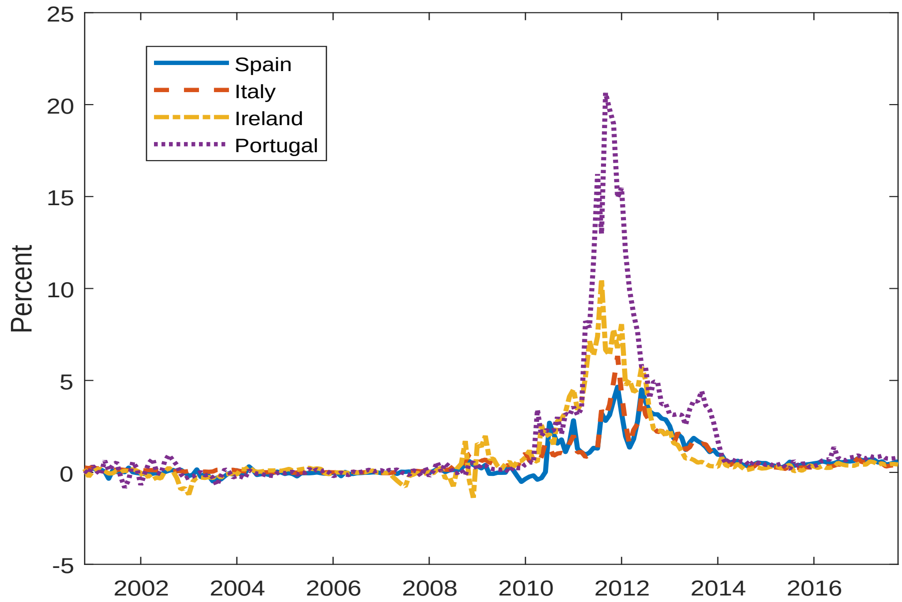

Figure 1.1: Sovereign Bond Spreads

In this paper, our benchmark economy is Spain, although we also provide results for Ireland, Portugal and Italy – all of them archetypal economies which suffered some of the most severe economic shocks in the aftermath of twin global financial crisis and eurozone debt crisis. After a lengthy property bubble burst in 2008, economic growth rate plummeted and Spain entered recession.[2] As Figure 1.2 shows it, amidst stagnating economy, bank lending to Non-Financial Institutions (NFIs) saw a huge drop. In concert with contraction in bank credit, investment and output fell markedly and were accompanied by a pronounced dip in consumption and a sharp and prolonged increase in number of people out of work.[3] Given the complex and multi-faceted nature of eurozone debt crisis, there is still no consensus on what caused this decline in bank lending and what its real effects were.

There are multiple channels through which sovereign debt crisis could have affected the banking sector and the real economy. One is so called "balance sheet channel" wherein banks' balance sheets were impaired after a reduction in value of their sovereign debt (see, e.g., Gennaioli, Martin and Rossi 2014, Sosa-Padilla 2017, Brunnermeier et al. 2016 and Bocola 2016). Another channel is moral suasion under which the eurozone economies hit by sovereign debt crisis might have explicitly or implicitly pressured their domestic banks to take up higher amounts

[2]Spain has historically had high home ownership rates. Home ownership rate exceeded 87% in 2007. Source: https://www.theatlantic.com/business/archive/2013/10/to-hell-and-back-spains-grotesque-recession-and-its-surprising-new-economy/280678/.

[3]At the height of the crisis unemployment rate hovered above 26 percent, a record high, with nearly 6 million people out of work. This rate was more than double at 60 percent for under-25 year olds (source: see, among others, https://www.ft.com/content/ecff6e4c-9c1f-11e6-a6e4-8b8e77dd083a).We mention unemployment here and have it as a variable in our empirical exercise to demonstrate the severity of the crisis on wider economic situation in Spain. Our theoretical model, however, excludes unemployment and focuses on banking sector and real economy which is the goal of this paper.

of domestic sovereign bonds in order to tide over their debt refinancing difficulties (Reinhart and Sbrancia 2015, Ongena, Popov and Van Horen 2016, Chari, Dovis and Kehoe 2014, Altavilla, Pagano and Simonelli 2017 and Becker and Ivashina 2017). This could have resulted in crowding out of bank lending to private firms. Yet another explanation is that weakly capitalized banks with prior exposure to sovereign debts in these economies were incentivized to scale up their risky holdings (the risk-shifting channel). This might again lead to crowding out of private debt and a portfolio shift to higher amounts of risky government debt (see, among others, Uhlig 2014, Acharya and Steffen 2015, Crosignani 2017 and Farhi and Tirole 2017)[4]. Our goal in this paper is to explore the machanism through which rising volatility of spread on government bonds played a role in decline in bank lending to domestic non-financial institutions (NFIs) and had negative impact on economic aggregates.

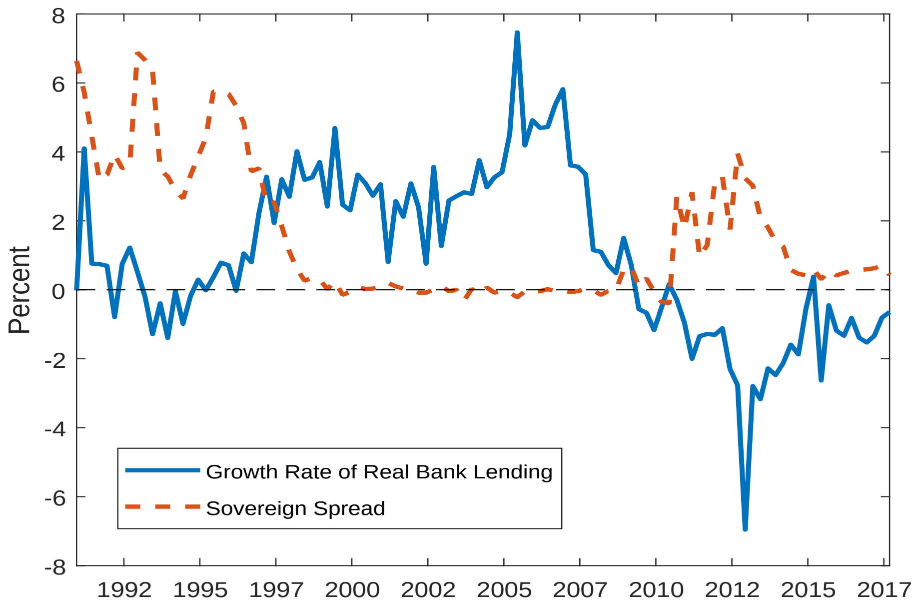

Figure 1.2: Sovereign Spread and Growth Rate of Bank Lending for Spain

Our results show that after a shock to the volatility of the sovereign spread, bank lending decreases. In the aftermath of the volatility surge, output, consumption and investment fall too. We find that a volatility shock impairs the bank's balance sheet and restricts its lending ability. These effects work through a decline in bank net worth following a reduction in value of its assets. Given that a sizable proportion of firms depend on bank credit for their financing needs, they significantly cut back their investment and output in the case of funding scarcity.[5]

We begin by empirically documenting using SVAR-SV techniques as in Mumtaz and Zanetti (2013) that volatility shocks to sovereign spread contributed to fall in bank lending. The

[4]See Abad (2018) for a model of feedback loop between sovereign and banking crises.

[5]While during eurozone debt crisis, both lower credit demand and lower credit supply are likely to play a role, a significant body of empirical work documents that bank credit did contract during this period (Popov and Van Horen 2014, Bottero, Lenzu and Mezzanotti 2015, De Marco 2017, Bofondi, Carpinelli and Sette 2017 and Acharya et al. 2018).

observed responses in the empirical exercise are very persistent, indicating that economic effects of volatility shocks last several years. While we focus on our benchmark economy Spain, we remarkably obtain similar results for Ireland, Portugal and Italy. These effects are qualitatively and quantitatively comparable across the four economies.

After quantifying the effects of volatility shocks in our empirical exercise, we rationalize these results in a theoretical model. We build a New Keynesian DSGE model augmented with a banking sector in the spirit of Gertler and Karadi (2013). We calibrate/estimate the model and find that after a positive shock to sovereign spread volatility, both the price of government bonds and the relative price of capital decline.[6,7] This is so because now banks find riskier to hold government bonds as they are exposed to larger fluctuations (either positive or negative) in the sovereign spread. The drop in asset prices pulls down bank net worth. Consequently, banks' ability to lend to firms is severely limited since their credit capacity is directly tied to their net worth. Firms in the domestic economy rely on bank credit to finance and run their operations. Lack of sufficient amount of bank credit, thus, creates scarcity of capital for firms and restricts investment and output.

Finally, our results suggest that contraction in bank credit after a volatility shock is contingent on amount of bank exposure to government bonds and its degree of leverage. Banks with greater exposure to sovereign debt suffer steeper fall in their net worth and hence, curtail lending more than the bank with lesser exposure. Likewise, more leveraged banks are more vulnerable to volatility shocks and scale down lending more than less leveraged banks in the wake of a spread volatility shock.

Our paper contributes to two strands of literature. In studying the impact of the sovereign spread volatility shock and its concomitant effects, it speaks to a developing body of work on the effects of crises on bank lending and its ensuing effects on the macroeconomy. For 2008-09 crisis that originated in the US, Chodorow-Reich (2013) show that firms linked with banks that had impaired balance sheets, had lower probability of obtaining a loan post-crisis and cut back employment more than firms connected with healthier banks. Using matched customs and firm-level bank credit data from Peru, Paravisini et al. (2014) find that credit shortages during 2008-09 led to a reduction in exports through an increase in variable cost of production. For Spain, Bentolila, Jansen and Jiménez (2017) document that more jobs were lost during 2008-09 at firms exposed to weak banks than at those working with stronger banks. Cingano, Manaresi and Sette (2016) show that Italian banks with more exposure to negative liquidity shock in the wake of 2008-09 crisis, tightened credit supply more than their healthier counterparts and this lower credit availability had a negative implication for a range of firm outcomes such as

[6] We model sovereign spread volatility shocks exogenously. This assumption is not a serious limitation of our model. Longstaff et al. (2011), for instance, investigate credit default swaps (CDS) for 26 economies and find that country spreads are driven more by forces exogenous to the economy than the local forces. Further support for this position comes form Uribe and Yue (2006) who show that innovations exogenous to the local conditions can explain up to two-thirds of movement in country spreads.

[7] In a reduced version of the model, we also perform a simulation assuming that shocks to the level and volatility of the spread are correlated as the empirical analysis suggests. This exercise reinforces our point that the sovereign spread volatility shock has a sizable impact on the banking sector since the effects of level and volatility shocks go in the same direction. Results are available upon request from the authors.

investment and employment.

Concerning the eurozone debt crisis, Popov and Van Horen (2014) provide evidence that during eurozone debt crisis, lending by non-GIIPS (Greece, Ireland, Italy, Portugal and Spain) banks with significant GIIPS sovereign bonds on their balance sheet, declined more relative to non-exposed banks. De Marco (2017) presents similar evidence confirming that bank exposure to sovereign debt led to a credit-tightening and had adverse effects on young and small firms. Using Italian credit register data, Bofondi, Carpinelli and Sette (2017) document that sovereign crisis led Italian banks to limit credit supply. Balduzzi, Brancati and Schiantarelli (2018) further support this finding and document that adverse changes to banks' market valuations resulted in lower investment, employment and bank credit for younger and smaller firms. These studies, however, do not explore which channels caused the contraction in lending and its consequences for the real economy. We seek to fill this gap through our paper.

The other body of literature our paper is related to concerns macroeconomic impact of uncertainty and second moment shocks. There is a burgeoning literature on this subject starting with Bloom (2009) who demonstrated by building a model with time-varying second moment and estimating it using firm-level data that uncertainty shocks generate sharp recessions and recoveries. Using a sample of four small open economies – Argentina, Ecuador, Venezuela and Brazil – Fernández-Villaverde et al. (2011) show that an increase in volatility of real interest rate at which these economies borrow can result in quantitatively important drops in macroeconomic aggregates. Born and Pfeifer (2014) estimate a New Keynesian model and measure risk from aggregate data for the US and find that policy risk plays a minor role in business cycle fluctuations. Fernández-Villaverde et al. (2015), on the other hand, investigate unexpected changes in the uncertainty surrounding fiscal policy in the US and reach the conclusion based upon their VAR evidence and New Keynesian model that volatility shocks could have significant negative effects on the macroeconomy through an endogenous rise in firms' markups. More recently, Bloom et al. (2018) document that uncertainty rises during recessions and it can generate drops to the tune of 2.5% in their DSGE model with heterogeneous firms. We do study effects of second moment shocks like the previous studies but we differ from them in focussing on effects of volatility shocks to sovereign spread. In this work we are interested in exploring how second moments shocks to sovereign spread could have real consequences for banking sector and might propagate its impact to larger macroeconomy.

The rest of this paper is structured as follows: section 1.2 presents SVAR-SV specification and results, illustrating the empirical support for our exercise. Section 1.3 contains a NK DSGE model with a banking sector which we use to rationalize our findings. Section 1.4 concludes.

1.2 Evidence from SVAR with Stochastic Volatility

Motivated by the patterns in Figure 1.1 and Figure 1.2, we estimate a VAR-SV to study and quantify how the peripheral eurozone economies respond to a sovereign spread volatility shock. We follow the specification in Mumtaz and Zanetti (2013) which permits time-varying shock volatility and allows it to have a direct impact on the level of endogenous variables.[8] Differently from them, however, we rely on a Cholesky decomposition for identification. The observables are ordered as follows: sovereign spread, growth rate of real bank lending to NFIs, real GDP growth, real investment growth, real private consumption growth and unemployment rate over the period 1990Q3 to 2017Q3. Data sources and definitions are listed in Appendix A.1. In what follows, we present a brief description of our key equations.

The VAR-SV is specified as follows:

$$Y_t = c + \sum_{k=1}^{2} \beta_k Y_{t-k} + \sum_{k=0}^{1} \phi_k \tilde{x}_{t-k} + \Omega_t^{1/2} \epsilon_t\,, \quad \epsilon_t \sim \mathcal{N}(0,\, 1), \tag{1.1}$$

where

$$\Omega_t = A^{-1} X_t A^{-1\prime}. \tag{1.2}$$

Here, Y_t represents the vector of endogenous variables and $\tilde{x}_t$ denotes the log-volatility of the structural shocks. The matrix A is set to identify the sovereign spread volatility shock based on a recursive identification and the representation of X_t is given by:

$$X_t = diag\big(e^{x_{spread,t}},\, e^{x_{loans,t}},\, e^{x_{gdp,t}},\, e^{x_{invest,t}},\, e^{x_{cons,t}},\, e^{x_{unemp,t}}\big).$$

The transition equation for the stochastic volatility is given by:

$$\tilde{x}_t = \alpha \tilde{x}_{t-1} + \nu_t, \quad \nu_t \sim \mathcal{N}(0,\, Q), \quad \mathbb{E}(\epsilon_t, \nu_t) = 0. \tag{1.3}$$

Note that the sovereign spread volatility does not appear as an endogenous variable in the VAR, which is consistent with our approach of modeling it as an exogenous process in our DSGE model. The previous non-linear state space model is estimated with a Gibbs sampling algorithm using 1,500,000 replications.[9] We discard the first 1,490,000 draws as burn-in and use the last 10,000 iterations for inference.

In Table 1.1, we provide the parameter estimates for the volatility process of the sovereign spread. The autocorrelation coefficient, α, is large for all the four economies with its value slightly lower for Portugal at 0.8514. This indicates that volatility of sovereign spreads are highly persistent across the four economies. Likewise, the variance of the process, Q, is also large for the group of countries we consider. In this case, we have Spain and Ireland with values 0.4635 and 0.4575 respectively, while Portugal and Italy with lower values of 0.3816 and 0.3634 respectively.

Figure 1.3 plots the impulse responses of a two standard deviation shock in the sovereign spread volatility to bank lending, output, investment, consumption and unemployment for

[8]This model resembles Primiceri (2005) and Cogley and Sargent (2005), among others. It can be seen as a multivariate extension of Koopman and Hol Uspensky (2002) which is a univariate stochastic volatility-in-mean model. Chan (2017) is another such model. Other multivariate extensions include Mumtaz (2011), Jo (2014) and Shin and Zhong (2018).

[9]Our algorithm follows Mumtaz and Zanetti (2013). We refer the reader to their Appendix A for further details.

Table 1.1: Parameter Estimates

	Spain	Ireland	Portugal	Italy
Autocorrelation (α)	0.9707	0.9505	0.8514	0.9669
	(0.9446, 0.9892)	(0.9143, 0.9790)	(0.7131, 0.9315)	(0.9442, 0.9850)
Variance (Q)	0.4064	0.4413	0.3816	0.3634
	(0.2324, 0.7028)	(0.2640, 0.7317)	(0.2045, 0.7530)	(0.2206, 0.6079)

Note: Each entry refers to the posterior medians of the parameters for the sovereign spread volatility shocks. The 68% confidence intervals for each parameter are shown in parenthesis.

Spain. We can observe that two standard deviation shock increases the log-volatility of the spread by around 130%. Yet, the estimated volatility shock (shown in Appendix A.3) increased during the eurozone debt crisis by more than 200%. Our results, therefore, provide a lower bound to the effects of volatility shocks.

After a positive volatility shock, all the variables decline except unemployment which shoots up to about 0.4% and remains elevated until around 18 quarters after which it begins its downward trajectory. This is in line with long and stubborn unemployment observed in Spain. Output begins declining and does not hit bottom until 10 quarters when it reaches its lowest value of -0.2%. Consumption and investment follow similar path and take 10 and 8 quarters before reaching their lowest points of around -0.2% and -0.7%, respectively. Bank lending also falls and keeps on decreasing until about 11 quarters, reaching a value of around -0.9%. In summary, we observe significantly negative effects of volatility shocks and their impact is long-lived.

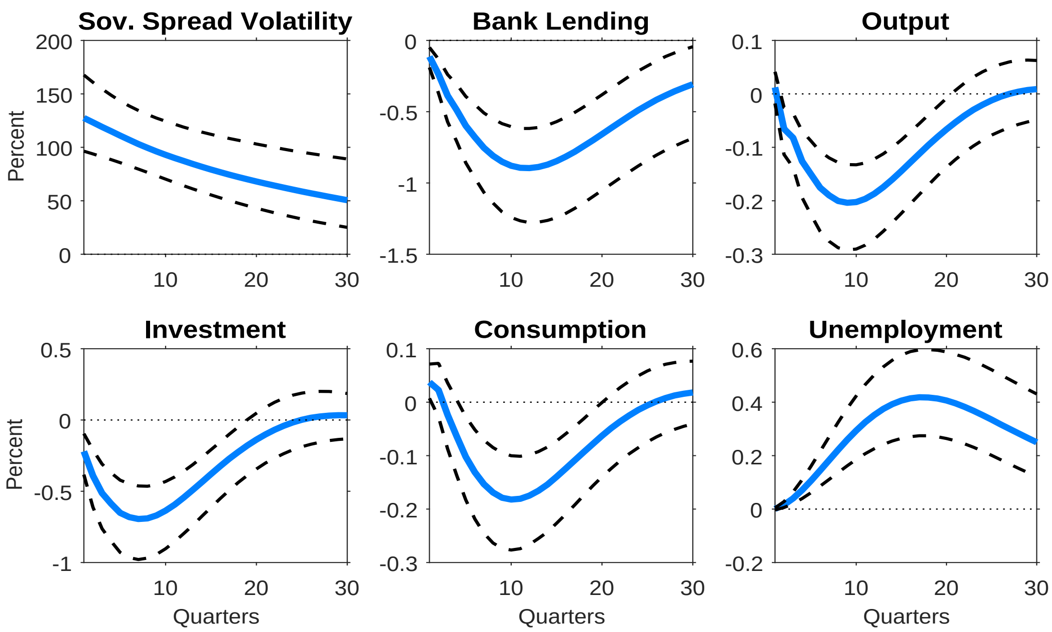

Figure 1.3: Impulse Responses from Estimated SVAR-SV, Spain
Note: Each entry shows the median and the 68% confidence bands.

Interestingly, the effects seen in Spain replicate themselves in Ireland and Portugal and to a lesser extent, Italy. In Ireland (see Figure 1.4), after a volatility shock, bank lending declines almost 0.25% and remains depressed for over 16 quarters before it shows signs of returning towards its previous level. Output and consumption both fall at impact and remain below their previous level for more than 30 quarters. Investment falls after the shock but rebounds to its previous level in about 13 quarters. Unemployment, on the other hand, rises about 0.2% in 14 quarters after which it starts declining. Portugal (Figure 1.5) witnesses similar affects in the aftermath of volatility shocks. Output, investment and consumption - all drop after impact but return rather quickly to their previous levels in about 15 quarters. Bank lending responds negatively to the shock and declines by around 0.5%. It then climbs back to its previous level in about 30 quarters. Consistent with patters in data elsewhere, here too unemployment climbs up to a little shy of 0.2% in around 10 quarters and then it starts falling back. Lastly, for Italy (Figure 1.6), data tell qualitatively similar story. In the wake of volatility shocks, output falls more than 0.1%. Investment and consumption also decline close to 0.4% and 0.07%. Bank lending drops more than 0.25% whereas unemployment increases more than 0.1% and remain elevated until about 25 quarters.

Overall, these results paint a clear and consistent picture of volatility shocks to sovereign spread. In Spain, Ireland and Portugal, there is evidence of a sizable and persistent negative impact of the shock and to a lesser degree, these effects are present in the case of Italy too. In each case, bank lending falls in tandem with drop in investment, output and consumption.[10] The protracted nature of these effects helps explain the lasting economic slowdown in the concerned economies.

1.2.1 Summary of Empirical Evidence

Using a SVAR-SV methodology which allows the volatility of spread shocks to affect the level of macroeconomic variables, we establish three facts - first, volatility shocks to sovereign spread had persistent and quantitatively significant effects on bank lending to domestic non-financial firms in peripheral eurozone economies. Second, the effects of these shocks were not limited to the banking sector alone, rather they rippled through to the larger economy and led to a prolonged and significant slump in investment, output and consumption. At the same time, they were accompanied by a rise in unemployment in all the four economies considered. Third, to test how plausible our SVAR-SV results are, we subject them to robustness checks which they survive.

1.3 Theoretical Framework

In this section, we use a New Keynesian DSGE model with financial intermediaries to rationalize our empirical results. The model helps us to shed light on how volatility shocks to the sovereign spread can affect banking sector and cause a slump in the real economic activity.

[10] In order to test robustness of our findings, in Appendix A.4, we document that our results are unchanged with respect to the ordering of the variables, specially when sovereign spread is ordered last.

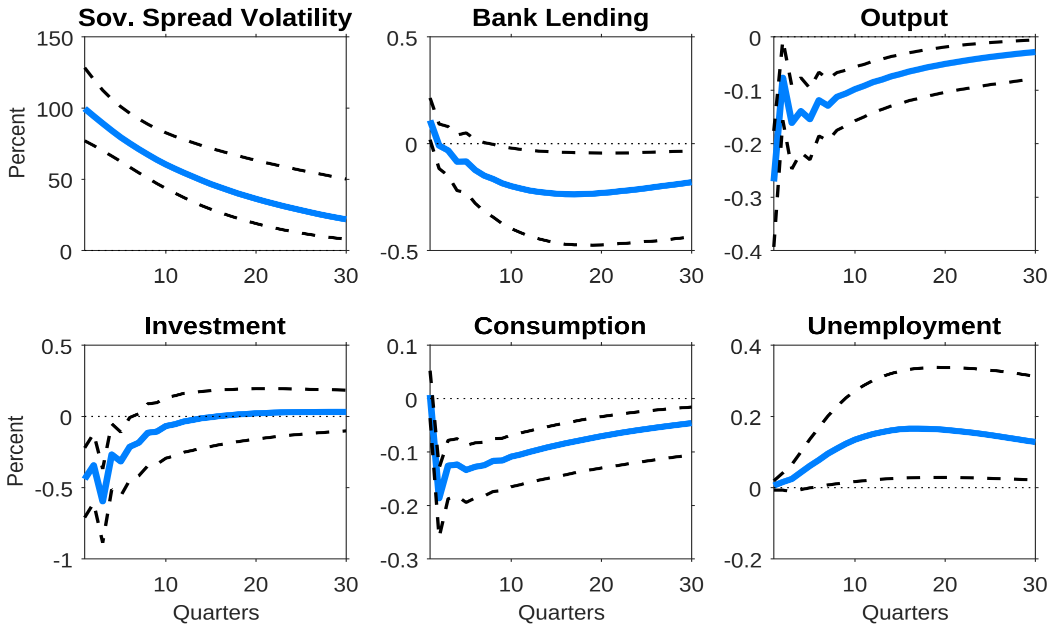

Figure 1.4: Impulse Responses from Estimated SVAR-SV, Ireland
Note: Each entry shows the median and the 68% confidence bands.

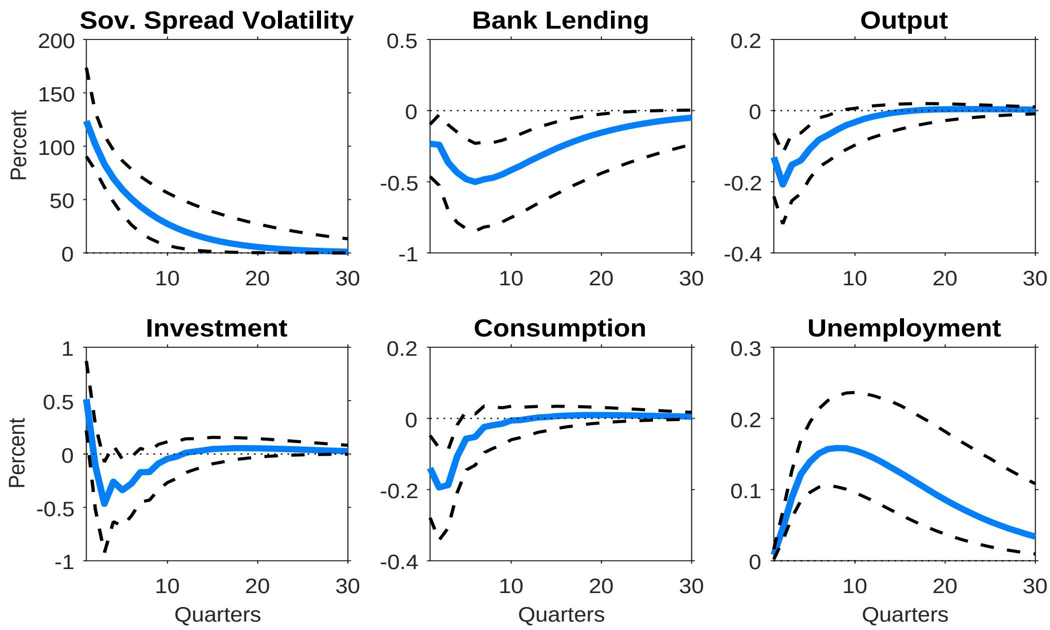

Figure 1.5: Impulse Responses from Estimated SVAR-SV, Portugal
Note: Each entry shows the median and the 68% confidence bands.

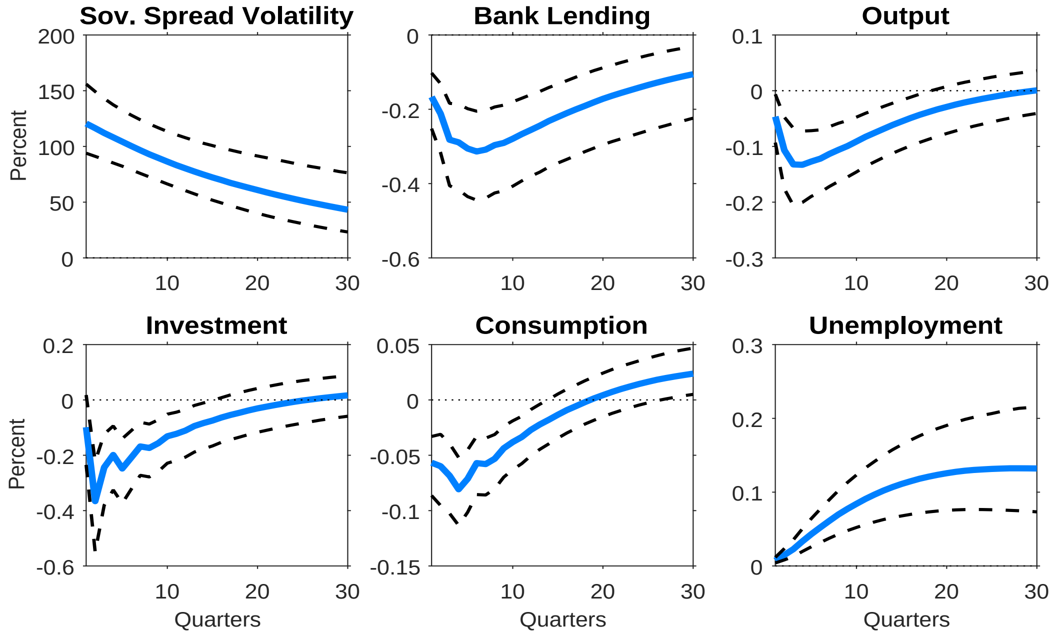

Figure 1.6: Impulse Responses from Estimated SVAR-SV, Italy
Note: Each entry shows the median and the 68% confidence bands.

1.3.1 New Keynesian DSGE with Banking Sector

In this section, we augment a canonical NK-DSGE model with financial intermediation as in Gertler and Karadi (2013).[11] In the model, banks hold government bonds. We will later relax this assumption and will allow households to directly hold bonds. We purposely model the return on these bonds as the sum of return on a perpetuity and an exogenous spread which is subject to a stochastic volatility shock. We defer a full description to the end of section.

Besides banks, the economy is inhabited by households, intermediate and retail goods firms, capital goods producers and a monetary authority. Each household comprises two types of members – workers and bankers. Workers supply labor to intermediate goods firms. Bankers combine their net worth with deposits from other households to buy claims on the firms and government bonds. Intermediate goods firms rent labor from workers and purchase capital from capital goods producers to produce a homogeneous product. Their capital expenses are financed by bankers. The retail goods firm aggregates the output of each intermediate firm. All goods firms and capital producers are owned by the households. The monetary authority sets the nominal interest rate. The following sections detail the agents' decision problems.

Households

Each household contains a constant fraction $(1 - f)$ of workers and a remaining fraction f of bankers. Workers supply labor to firms and transfer their wages to the household. Each banker

[11] An indicative list of other papers with similar models is Gertler and Kiyotaki (2010), Gertler and Karadi (2011), Gertler, Kiyotaki and Queralto (2012), Gertler and Kiyotaki (2015) and Akinci and Queralto (2017).

manages a bank and likewise returns net earnings to the household. A detailed description of banking sector is deferred to the next section. There is perfect consumption insurance within the family.

Households consume, save and pay lump-sum taxes. Additionally, they invest their savings in short-term bank deposits. The households maximize their utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{(C_t - hC_{t-1})^{1-\nu}}{1-\nu} - \chi \frac{H_t^{1+\psi}}{1+\psi} \right\}, \tag{1.4}$$

subject to the resource constraint:

$$C_t = R_{t-1} D_{t-1} - D_t + W_t H_t + \Pi_t + T_t. \tag{1.5}$$

On their deposits with financial intermediaries, D_t, the household receives a real interest rate, R_t. Besides, it supplies labor, H_t, for real wage rate, W_t. Its consumption is denoted by C_t. Through its ownership of goods and capital producing firms, the household receives the profit Π_t. Moreover, it is subject to lump-sum taxes, T_t.

Denoting by ϱ_t the Lagrange multiplier, the optimality conditions for household's maximization problem with respect to deposits, labor and consumption are:

$$1 = \mathbb{E}_t \Lambda_{t,t+1} R_{t+1}, \tag{1.6}$$

$$\chi H_t^{\psi} = \varrho_t W_t, \tag{1.7}$$

$$(C_t - hC_{t-1})^{-\nu} - h\beta \mathbb{E}_t (C_{t+1} - hC_t)^{-\nu} = \varrho_t, \tag{1.8}$$

where

$$\Lambda_{t,t+1} \equiv \beta \frac{\varrho_{t+1}}{\varrho_t}. \tag{1.9}$$

Firms

There are two types of firms in the economy – non-financial firms and financial firms. Non-financial firms include intermediate goods producers, retailers and capital goods producers. Financial firms refer to banks.

Non-financial Firms

Intermediate Goods Producers

Intermediate goods producers operate in a competitive environment and sell their output to retailers. At the end of period t, an intermediate goods producer acquires capital, K_{t+1}, which it uses for production in subsequent period. After production has taken place in period $t+1$, the firm has the option of selling the used capital on the open market.

To finance its capital acquisition every period, the firm obtains funds from financial intermediaries. It issues securities, S_t, equal to number of units of capital it acquires, K_{t+1}, and prices each claim at the unit price of capital, Q_t. Thus, Q_tS_t is the value of claims against the capital and Q_tK_{t+1} is the value of the capital. By arbitrage:

$$Q_tS_t = Q_tK_{t+1}. \tag{1.10}$$

Intermediate goods producers combine capital and labor using a constant returns to scale technology:

$$Y_t = A_tK_t^{\alpha}H_t^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{1.11}$$

where A_t is TFP with the following law of motion:

$$A_t = \rho_A A_{t-1} + \sigma_A u_{A,t}. \tag{1.12}$$

Here, $u_{A,t}$ is a normally distributed shock with zero mean and standard deviation σ_A. Letting P_{mt} be the relative price of intermediate goods at time t, the firm chooses labor to satisfy:

$$W_t = P_{mt}(1-\alpha)\frac{Y_t}{H_t}. \tag{1.13}$$

Assuming the firm makes zero profits every period, it pays out ex post return on capital to the banks. Therefore, R_{t+1}^k is given by:

$$R_{t+1}^k = \frac{P_{mt}\frac{\alpha Y_{t+1}}{K_{t+1}} + (1-\delta)Q_{t+1}}{Q_t}, \tag{1.14}$$

where δ is the gross depreciation rate. The law of motion for capital is given by:

$$K_{t+1} = \xi_{t+1}[I_t + (1-\delta)K_t], \tag{1.15}$$

where ξ_t is a random shock commonly used to induce variation in return to capital and is often called "capital quality" shock. Its law of motion is given as:

$$\xi_t = \rho_\xi \xi_{t-1} + \sigma_\xi u_{\xi,t} \tag{1.16}$$

where $u_{\xi,t}$ is a normally distributed shock with zero mean and standard deviation σ_ξ.

Retailers

There is a continuum of mass unity of differentiated retailers that use intermediate output as their sole input. Final output Y_t is a CES composite of retail firm's output and is given by:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{1.17}$$

where $Y_t(i)$ denotes output of the retailer i and ϵ is the elasticity of substitution among retail goods. The demand curve for each retail good is thus given by:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t. \tag{1.18}$$

Retailers repackage intermediate output and convert it into final output one-to-one. The relative intermediate output price P_{mt} is therefore the marginal cost. Retail goods firms are subject to quadratic pricing adjustment costs as in Rotemberg (1982) (expressed in terms of deviations from steady-state inflation rate). The retail goods firm i maximizes:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \Lambda_{t+j} \left(\frac{P_{t+j}(i) - P_{mt}}{P_{t+j}} Y_{t+j}(i) - \frac{\phi_P}{2} \left(\frac{P_{t+j}(i)}{P_{t+j-1}(i)} - \pi \right)^2 Y_{t+j} \right), \tag{1.19}$$

subject to the demand function in Equation 1.18.

Capital Goods Producers

Capital producers use input of final goods to make new capital. They sell new capital to investing firms at the price of Q_t. Capital producers choose I_t to solve:

$$\max\ \mathbb{E}_t \sum_{\tau=t}^{\infty} \Lambda_{t,\tau} \left\{ Q_\tau I_\tau - \left[1 + f\left(\frac{I_\tau}{I_{\tau-1}} \right) \right] I_\tau \right\}. \tag{1.20}$$

From profit maximization, the price of capital goods equals the marginal cost of investment goods production:

$$Q_t = 1 + f\left(\frac{I_t}{I_{t-1}}\right) + \frac{I_t}{I_{t-1}} f'\left(\frac{I_t}{I_{t-1}}\right) - E_t \Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t}\right)^2 f'\left(\frac{I_{t+1}}{I_t}\right), \tag{1.21}$$

where investment adjustment costs have the following functional form:

$$f\left(\frac{I_t}{I_{t-1}}\right) = \frac{\vartheta}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2. \tag{1.22}$$

Profits are rebated to the households in lump-sum.

Financial Firms

Banks

Banks are owned by households and run by bankers within them. Bankers raise deposits from households, D_t, and combine it with their net worth or equity capital, N_t, to buy claims on intermediate goods firms and invest in long-term government bonds. Their balance sheet reads as:

Assets	Liabilities
Q_tS_t	N_t
$Q_t^BB_t$	D_t

where S_t is the quantity of financial claims the bank has on intermediate goods firms and Q_t is the relative price of each claim. Amount of government bonds held by banks is denoted by B_t and their price by Q_t^B.

Bank's net worth accumulates through retained earnings and is the difference between what they earn on their lending to intermediate goods firms and investment in government bonds and what they pay to their deposit holders. It is, thus, given as:

$$N_t = R_t^kQ_{t-1}S_{t-1} + R_t^BQ_{t-1}^BB_{t-1} - R_tD_{t-1}, \tag{1.23}$$

where R_t^B is the return banks earn on their investment in government bonds and R_t is the interest rate they pay to their deposit holders.

We assume that each banker has a finite life and exits the market with a probability $1-\theta$ every period. Before exiting the market, a banker transfers its accumulated lifetime earnings back to its household. The bankers objective is to maximize the discounted present value of their terminal wealth:

$$V_t = \mathbb{E}_t\sum_{i=1}^{\infty}\Lambda_{t,t+i}(1-\theta)\theta^iN_{t+i}, \tag{1.24}$$

where $\Lambda_{t,t+i}$ is household's intertemporal marginal rate of substitution which bankers use as their discount factor.

As long as bank earns more on its lending to firms than it pays on its deposits, it has incentive to expand its assets indefinitely by accepting more deposits from households. In order to motivate a limit on its ability to do so, we impose a moral hazard problem. We assume that at the end of every period, a bank can divert a fraction λ of available funds from the project and transfer it back to its household. This leads to depositors forcing bank's liquidation and recovering remaining $1-\lambda$ of assets. Bank's continuation value, in this case, is given as:

$$V_t \geq \lambda(Q_tS_t + \Delta Q_t^BB_t), \tag{1.25}$$

where $0 > \lambda > 1$ and $0 > \Delta > 1$. We assume that a fraction λ of private assets and another fraction $\lambda\Delta$ of government bonds can be embezzled by the banks with $\lambda\Delta < \lambda$. This captures the assumption that it is easier for banks to divert a higher proportion of private assets than its government bond holdings and can be motivated by lower monitoring ability of deposit holders.

Let's denote the Lagrange multiplier on incentive constraint by φ_t and let $\tilde{\Lambda}_{t,t+1}$ be the bank's stochastic discount factor augmented by multiplier Ω_{t+1}:

$$\tilde{\Lambda}_{t,t+1} \equiv \Lambda_{t,t+1}\cdot\Omega_{t+1}. \tag{1.26}$$

The weight Ω_{t+1} is shadow value of a unit of net worth to the bank at $t+1$. It represents the marginal value of net worth averaged across exiting and continuing states and is given as:

$$\Omega_{t+1} = 1 - \theta + \theta \mathbb{E}_t \Lambda_{t,t+1}[(R^k_{t+1} - R_{t+1})\phi_t + R_{t+1}]. \tag{1.27}$$

In Equation 1.27, $1-\theta$ captures the probability that a banker exits and obtains a marginal unity of one because it transfers all its retained earnings to its household. With the complementary probability θ, the banker survives and expands its assets using its retained earnings. When excess returns on assets are positive, the marginal value exceeds unity.

The expected excess returns on banks assets are:

$$\mathbb{E}_t \tilde{\Lambda}_{t,t+1}(R^k_{t+1} - R_{t+1}) = \lambda \frac{\varphi_t}{1+\varphi_t}, \tag{1.28}$$

$$\mathbb{E}_t \tilde{\Lambda}_{t,t+1}(R^B_{t+1} - R_{t+1}) = \Delta\lambda \frac{\varphi_t}{1+\varphi_t}. \tag{1.29}$$

It's noteworthy here that excess returns on government bonds are smaller than those on loans by a factor of $\Delta < 1$. It is a consequence of the assumption that the proportion of government bonds that banks can divert is only a fraction Δ of their loans portfolio.

Bank's net worth is directly tied to its leverage, ϕ_t, and it places restrictions on the size of a bank's portfolio vis-a-vis its net worth:

$$Q_t S_t + \Delta Q^B_t B_t = \phi_t N_t \ \text{ if } \ \varphi_t > 0, \tag{1.30}$$

where time-varying leverage is written as:

$$\phi_t = \frac{\mathbb{E}_t \tilde{\Lambda}_{t,t+1} R_{t+1}}{\lambda - \mathbb{E}_t \tilde{\Lambda}_{t,t+1}(R^k_{t+1} - R_{t+1})}. \tag{1.31}$$

The time-varying leverage moves inversely with λ – an increase in it reflects banker's incentive to steal more which leads to lesser willingness on the part of depositors to supply funds. On the other hand, an increase in the discounted excess returns on the assets – be it on their loan portfolio, $\mathbb{E}_t \tilde{\Lambda}_{t,t+1} R_{t+1}$, or on their government bond holdings, $\mathbb{E}_t \tilde{\Lambda}_{t,t+1}(R^k_{t+1} - R_{t+1})$ – bolsters their franchise value and raises the amount bankers stand to lose by diverting a fraction of assets. It then inspires more confidence in depositors to supply funds to bankers and thus raises their leverage, ϕ_t.

Net worth of existing bankers evolves as sum of retained earnings by the surviving fraction θ of the bankers and is given as:

$$N_{et} = \theta \left[\frac{(R^k_t - R_t) Q_{t-1} S_{t-1}}{N_{t-1}} + \frac{(R^B_t - R_t) Q^B_{t-1} B_{t-1}}{N_{t-1}} + R_t \right] N_{t-1}. \tag{1.32}$$

A few observations are in order about Equation 1.32. Fluctuations in ex post returns on loans, R^k_t, and ex post returns on government bonds, R^B_t, are the driving forces behind variation in net worth, N_{et}. In addition, impact of this variation in returns increases in bank's degree of leverage as mirrored by ratios of respective assets to net worth, $Q_{t-1}S_{t-1}/N_{t-1}$ and, $Q^B_{t-1}B_{t-1}/N_{t-1}$.

As we will see later, after a volatility shock, fluctuations in returns will drive the drop in banks' net worth and will limit their ability to extend loans.

With probability θ, an existing banker exits the market and a fraction ω of its total value of assets is transferred to each new banker:

$$N_{nt} = \omega(Q_{t-1}S_{t-1} + Q^B_{t-1}B_{t-1}). \tag{1.33}$$

The aggregate net worth of bankers, N_t is simply the sum of net worth of existing bankers and that of new bankers:

$$N_t = N_{et} + N_{nt}. \tag{1.34}$$

As we mentioned before, banks' asset portfolio consists of long-term government bonds and loans to firms. For the moment, we assume that all the bonds are held only by the banks. Later, we will relax this assumption and will allow direct participation by households in the market for government bonds. We assume that every government bond is a perpetuity and pays one dollar per period indefinitely. The real rate of return on the bond is then given as:

$$R^B_t = \frac{(1/P_{t-1} + Q^B_t)}{Q^B_{t-1}} + u_{RB,t}, \tag{1.35}$$

where P_{t-1} is the price level in period $t-1$ and $u_{RB,t}$ is spread on the government bond. Appending this spread to real returns on government bonds is what gives us stochastic variation. The bond spread evolves as an $AR(1)$ process:

$$u_{RB,t} = \rho_{RB}u_{RB,t-1} + e^{\sigma_{RB,t}}u_{RB,t}, \tag{1.36}$$

where $u_{RB,t}$ is a normally distributed shock with mean zero and unit variance. Its standard deviation, $\sigma_{RB,t}$, obeys the following $AR(1)$ process:

$$\sigma_{RB,t} = (1-\rho_{\sigma_{RB}})\sigma_{RB} + \rho_{\sigma_{RB}}\sigma_{RB,t-1} + \eta u_{\sigma_{RB,t}}. \tag{1.37}$$

In the above equation, $u_{\sigma_{RB,t}}$ is a normally distributed shock with zero mean and unit variance. The parameters σ_{RB} and η control the degree of mean volatility and stochastic volatility, respectively in the bond spread.

Securities Holdings by Households

Until now, we assumed that government bonds and securities issued by intermediate goods firms were held by banks. In this section, we relax these assumptions by allowing households to hold these securities directly. In order to prevent households from engaging in frictionless arbitrage, we assume that household participation is subject to transaction costs.

We assume that when households' portfolio of private securities goes beyond a limit $\bar{S}^h$, they pay a cost equalling a percentage $\frac{1}{2}\kappa(S^h_t - \bar{S}^h)^2/S^h_t$ of the value of their portfolio exceeding this limit, $S^h_t > \bar{S}^h$. This formulation of the transaction costs captures the assumption that below a limit, households can costlessly engage in transactions for holding assets but once they go above this limit, they pay costs which increase at the margin. This assumption captures limited participation by households in asset markets and is a robust feature of micro data. Similarly, there is a holding cost for government bonds too which equals the percentage $\frac{1}{2}\kappa(B_t^h - \bar{B}^h)^2/B_t^h$ of the total value of the government bonds for $B_t^h > \bar{B}^h$.

After we allow for direct holdings of private securities and government bonds by households, their balance sheet reads as:

$$\begin{aligned} C_t + Q_t \left[S_t^h + \frac{1}{2}\kappa(S_t^h - \bar{S}^h)^2/S_t^h \right] + Q_t^B \left[B_t^h + \frac{1}{2}\kappa(B_t^h - \bar{B}^h)^2/B_t^h \right] \\ = R_{t-1}D_{t-1} - D_t + R_t^k S_{t-1}^h + R_t^B B_{t-1}^h + W_t H_t + \Pi_t + T_t. \end{aligned} \tag{1.38}$$

Solving the households' optimization problem in this case with the new budget constraint leads to the same optimal choices for deposits, labor supply and consumption as in Equation 1.6, Equation 1.7 and Equation 1.8. The optimality conditions for securities and government bonds read as:

$$S_t^h = \bar{S}^h + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{t+1}^k - R_{t+1})}{\kappa}, \tag{1.39}$$

$$B_t^h = \bar{B}^h + \frac{\mathbb{E}_t \Lambda_{t,t+1}(R_{t+1}^B - R_{t+1})}{\kappa}. \tag{1.40}$$

It can be observed from the above two equations that demand for each asset above its frictionless capacity ($\bar{S}^h$ and $\bar{B}^h$ respectively) is increasing in its excess return relative to the respective curvature parameter governing the marginal transaction cost. When marginal costs drop to zero, excess returns disappear and households can engage in frictionless arbitrage of security returns. Conversely, when marginal costs rise to infinity, households demand their respective frictionless capacity values.

The asset demand by households, as outlined above, captures an important fact. In reality, a significant proportion of firms are able to raise money directly from general public. These are typically older and larger firms and solicit funds on the open market though initial public offerings (IPOs) or seasoned equity offerings (SEOs). Additionally, households may differ in varying degree in their ability to hold and manage asset portfolios. A limited supply of these "sophisticated" households makes frictionless arbitrage of asset returns by households impossible. Taken together, these two forms of heterogeneity (in firms and households) help explain why asset holdings might be divided between banks and households.

With households' direct participation in the assets markets, the new equilibrium conditions in the market for loans and government bonds read as:

$$S_t = S_t^b + S_t^h, \tag{1.41}$$

$$B_t = B_t^b + B_t^h, \tag{1.42}$$

where S_t^b and B_t^b are amounts of private securities and government bonds respectively held by banks. Household holdings are denoted by S_t^h and B_t^h respectively, as before.

Government Policy, Resource Constraint and Equilibrium

The government expenditure, G_t, is supposed to be fixed:

$$G_t = \bar{G}. \tag{1.43}$$

Monetary policy is characterized by a simple Taylor rule which is given as:

$$i_t = i + \kappa_\pi \pi_t + \kappa_y (\log Y_t - \log \bar{Y}) + \upsilon_{i,t}, \tag{1.44}$$

where i_t is the net nominal interest rate, i steady-state interest rate and $\bar{Y}$ the output in the steady state. The monetary policy is subject to an exogenous shock, $\upsilon_{i,t}$, that obeys the following $AR(1)$ process:

$$\upsilon_{i,t} = \rho_i \upsilon_{i,t-1} + \sigma_i u_{i,t}, \tag{1.45}$$

where $u_{i,t}$ is a normally distributed shock with zero mean and standard deviation σ_i. The relationship between the nominal and the real interest rate is given by the following Fisher equation:

$$1 + i_t = R_{t+1} \frac{P_{t+1}}{P_t}. \tag{1.46}$$

The economy-wide resource constraint is given as

$$Y_t = C_t + \left[1 + f\left(\frac{I_t}{I_{t-1}}\right)\right] I_t + \frac{\phi_P}{2}\left[\frac{P_t}{P_{t-1}} - \pi\right]^2 Y_t + G_t. \tag{1.47}$$

The supply of private securities at the end of period t is given by:

$$S_t = I_t + (1 - \delta) K_t, \tag{1.48}$$

which is the sum of newly acquired capital, I_t, and leftover capital, $(1 - \delta)K_t$.

The supply of long-term bonds is fixed by the government:

$$B_t = \bar{B}. \tag{1.49}$$

And finally, labor market attains equilibrium by requiring the labor demand equals labor supply, that is:

$$(1 - \alpha)\frac{Y_t}{H_t} \cdot \varrho_t = \frac{1}{P_{mt}} \chi H_t^{\psi}. \tag{1.50}$$

1.3.2 Solving the Model and Calibration

The model is solved nonlinearly through perturbation methods.[12] We are interested in examining the impact of volatility shocks while keeping the level of sovereign returns unchanged. As discussed in Fernández-Villaverde et al. (2011), we need a third-order approximation of policy function. A first-order approximation to the model misses the volatility dynamics because of

[12] We make use of Dynare (Adjemian et al. 2011).

certainty equivalence. A second-order approximation captures volatility only indirectly through cross-product of error terms. In a third-order approximation, stochastic volatility shocks enter as independent arguments in the policy function. Hence to explore the direct role of volatility, we need to consider cubic terms.

For calibration of parameters, we bifurcate the model parameters into two groups. In the first group, parameters are calibrated using steady state relationships or results from literature. For the second group, we estimate parameters using a combination of impulse and moment matching which we will describe shortly.[13] Table 1.2 lists the parameters taken from the literature and some of the other parameters estimated by impulse and moment matching. The remaining estimated parameters for exogenous processes are gathered in Table 1.3.

Drawing upon Gertler and Karadi (2013), we set the values of the following parameters: gross depreciation rate for capital goods firms, δ; capital share in production for intermediate goods firms, α; survival rate of new bankers, θ; proportional advantage in seizure rate of government bonds, Δ; portfolio adjustment cost, κ; inflation coefficient in the Taylor rule, κ_π, and output coefficient, κ_y. Transfer to new bankers, ω, is assigned a small number 0.001 which is close to the value of 0.002 used in Gertler and Karadi (2011). The parameter for elasticity of demand, η, and inverse of Frisch elasticity of labor, ψ, come from Fernández-Villaverde et al. 2015. Similar to Basu and Bundick (2017), price adjustment cost, ϕ_P, is chosen to be 100 so that in an equivalent Calvo (1983) setup, prices are fixed for 4 quarters on average. The household discount factor, β, is given a standard value of 0.990. We choose K^h so that households hold half of total private securities in the steady state (as in Gertler and Karadi 2013), and B^h so that households hold 65% of the outstanding stock of government debt (as seen in data for 2012). Autocorrelation parameter of the shock to the volatility of spreads on government bonds, $\rho_{\sigma_{RB}}$, and stochastic volatility parameter, η, are set from the estimated SVAR-SV.

For the second group of parameters, we employ a combination of impulse response and moment matching. The goal here is to minimize the distance between impulse responses implied by model and empirical responses generated by data. Specifically, we write our estimator, j as:

$$j = \min_{\gamma} [\hat{\psi} - \psi(\gamma)]' V^{-1} [\hat{\psi} - \psi(\gamma)] + \zeta [\hat{\Xi} - \Xi(\gamma)]' W^{-1} [\hat{\Xi} - \Xi(\gamma)], \tag{1.51}$$

where $\hat{\psi}$ denotes empirical impulse responses obtained from the SVAR-SV, $\psi(\gamma)$ is the model responses to a spread volatility shock and γ is the 13×1 vector of estimated parameters which includes investment adjustment costs, ϑ; fraction of divertible assets, λ; inverse elasticity of intertemporal substitution, ν; habit parameter, h; steady state government bond supply, $\bar{B}$, and parameters of exogenous shocks. We refer to their estimated values by "target" in Table 1.2 and Table 1.3. V is a diagonal matrix with the variances of the empirical impulse responses. $\hat{\Xi}$ and $\Xi(\gamma)$ are the vectors that contain the unconditional standard deviations of output, consumption, investment and bank lending in the data and in the model, respectively. W is a diagonal matrix that contains the empirical unconditional variances of the economic aggregates. The parameter

[13] See Basu and Bundick (2017) and Christiano, Eichenbaum and Evans (2005) for similar parameter calibration and estimation approach.

Table 1.2: Calibration Values for Spain

	Capital goods firms		
ϑ	Investment adjustment cost	28.310	Target
δ	Gross depreciation rate	0.025	Gertler and Karadi (2013)
	Intermediate and final goods firms		
α	Capital share in production	0.330	Gertler and Karadi (2013)
ϵ	Elasticity of demand	21	Fernández-Villaverde et al. (2015)
ϕ_P	Price adjustment cost	100	Calvo (1983) price stickiness of 0.75
	Banks		
λ	Fraction of divertible capital	0.337	Target
ω	Transfer to new bankers	0.001	Small value
θ	Survival rate of bankers	0.972	Gertler and Karadi (2013)
Δ	Proportional advantage in seizure rate of gov. bonds	0.500	Gertler and Karadi (2013)
	Households		
β	Discount rate	0.990	Standard
ν	Inverse elasticity of intertemporal substitution	2.297	Target
h	Habit formation	0.240	Target
ψ	Inverse of Frisch elasticity of labor	0.500	Fernández-Villaverde et al. (2015)
K^h/K	Proportion of direct capital holdings of the households	0.500	Gertler and Karadi (2013)
B^h/B	Proportion of gov. bond holdings by households	0.650	Data, average 2012
κ	Portfolio adjustment cost	1	Gertler and Karadi (2013)
	Monetary Policy and Government bond Supply		
κ_π	Inflation coefficient Taylor rule	1.500	Gertler and Karadi (2013)
κ_y	Output coefficient Taylor rule	0.125	Gertler and Karadi (2013)
$\bar{B}$	Gov. bond supply	1.196	$B/Y = 0.85$ (Data, average 2012)
$\bar{G}/Y$	Gov. Consumption	0.202	(Data, average 2012)

ζ is chosen to be 600 to roughly equalize the weight on matching the unconditional moments and impulse response functions.

To compute model moments, we first simulate the model for 10,000 periods and discard the first 9,891 iterations as burn-in. We use the last 109 periods to compute model moments and repeat this procedure 250 times to take the mean of the moments of the simulation. For generating data moments, we detrend the log of each empirical time series using the HP filter with a smoothing parameter set to 1600.

Table 1.4 shows the values that we obtain from the model and those that we observe in the data. Evidently, the model does a fairly good job at matching the data moments. For instance, standard deviation of output in the model is 1.1905 which is close to the value 1.3140 generated by data. Similarly, values of standard deviation implied by the data for consumption

Table 1.3: Calibration Values of Exogenous Processes for Spain

Shocks			
$\rho_{\sigma_{RB}}$	Autocorrelation parameter of σ_{Rb}	0.9659	Estimated SVAR
η	Stochastic volatility parameter	$(0.4064)^{\frac{1}{2}}$	Estimated SVAR
ρ_{RB}	Autocorrelation parameter of Rb	0.9517	Target
σ_{RB}	Degree of mean volatility	-8.8138	Target
ρ_A	TFP autocorrelation	0.9575	Target
σ_A	Standard deviation of TFP	0.0019	Target
ρ_ξ	Capital quality autocorrelation	0.9263	Target
σ_ξ	S.D. of capital quality shock	0.0004	Target
ρ_i	Taylor rule autocorrelation	0.5938	Target
σ_i	Taylor rule standard deviation	0.0037	Target

and investment are 1.5092 and 4.0190 which are not far away from the values 1.1871 and 4.5552 generated by model. We obtain a slightly less but still good fit for bank lending. Given that we have stochastic volatility in exogenous shocks of our model, the endogenous variables also show time-varying volatility. Here also, the model successfully reproduces responses which are consistent with and are representative of observations in data. We do, however, note that it is challenging to match the stochastic volatility observed in data with that implied by the model for output. While Table 1.4 summarizes results for Spain, we obtain similar results for Ireland, Portugal and Italy which we do not include here in the interest of space.

Table 1.4: Model versus Data for Spain

Variable	Standard Deviation		Stochastic Volatility	
	Model	Data	Model	Data
Output	1.1905	1.3140	0.2513	0.4529
Consumption	1.1871	1.5092	0.3100	0.4283
Investment	4.5552	4.0190	1.1342	1.3964
Bank Lending	4.0221	3.5112	0.7298	0.8723

Note: The empirical sample period is 1990-2017. Stochastic volatility is measured using the standard deviations of the time series estimate for the 5-year rolling standard deviation.

1.3.3 Results

We now explore how well the model-generated impulse responses match those from data. Figure 1.7 shows impulse responses to a two standard deviation shock in the sovereign spread volatility for Spain. As is evident from a look at the impulse responses, after the shock hits the economy, bank lending, net worth, output, consumption and investment – all fall. Output and consumption drop by close to 0.2% while investment falls by around 0.6%. Bank lending plunges by more than 0.3%. If one compares these impulse responses to those in Figure 1.3, it is abundantly clear that our DSGE model does a reasonably good job of matching the patterns in data. Except for bank lending for which there is evidence of a greater decline in data (it declines by close to 0.9%), behaviour of other aggregate economic variables in our DSGE model is, notably, in line with what we observe empirically.

A way to understand these results is that, after a volatility shock, the price of government bonds decline because now it becomes riskier to hold them as banks start to be exposed to larger fluctuations in the sovereign spread (either positive or negative). At the same time, the relative price of private capital falls too. Given the tightening of bankers' constraints, they start perceiving firms' claims more uncertain, therefore they reduce their private sector holdings.

Figure 1.7: Impulse Responses from DSGE with Financial Intermediaries, Spain

To see how erosion in banks' net worth squeezes borrowing firms' economic activities, consider first the relationship between banks' portfolio and net worth:

$$Q_t S_t^b + \Delta Q_t^B B_t^b = \phi_t N_t.$$

Net worth of banks is tied up with their lending activities. The drop in Q_t^B and Q_t impairs banks' balance sheets, causing a drop in banks' net worth, N_t. The endogenous leverage, ϕ_t, increases given that reduction in net worth is much greater than the decline in bond holdings and bank lending. This is because in our model we do not distinguish between outside and inside equity as in Gertler, Kiyotaki and Queralto (2012), implying that banks can only use short term deposits to finance their assets.[14] In this environment, N_t (inside equity), is highly susceptible to fluctuations in asset values, which prevents the decline in N_t from being cushioned by outside equity. Furthermore, associated with the drop in inside equity, there is a surge in the expected excess return on capital (motivated by the riskier perception of private firm's claims). Higher excess return to capital implies higher cost of capital and consequently, investment and real activity will be lower than what it would otherwise be.

To understand better how the effects of volatility shocks propagate to real economy, consider the following relationship between value of capital held by intermediate goods firms and the claims held by banks against them:

$$Q_t S_t = Q_t K_{t+1}.$$

Firms' capital acquisition and their ability to run operation is closely reliant upon securing credit from banks.[15] Since banks reduce their demand for securities in the aftermath of rising spread volatility, firms' investment acquisition plans suffer, leading to a contraction in real activity. We can also observe in Figure 1.7 that net worth recovers faster than bank assets, and thus causing

[14] Gertler, Kiyotaki and Queralto (2012) consider two different liabilities that banks can offer to households: deposits and equity, which they argue that may be interpreted as state contingent debt. They refer to equity issued by banks and held by households as outside equity.

[15] In our model economy, we mainly allow households to hold private securities to better match the IRF of bank lending with data. Then, total private securities is equal to the sum of the ones held by banks and households.

the slow recovery in real variables. Then, as noted in Gertler and Karadi (2011), the need for this deleveraging can delay the recovery of the economy.

Banks' Exposure to Government Bonds

In this section and the next, we explore the transmission channels for the observed negative effects after a spread volatility shock. First, we focus on the banks' varying exposure to government bonds. Before the advent of the eurozone debt crisis, the share of government bonds held by domestic banks was about 20% in 2007. It rose sharply to 35% by 2012.[16]

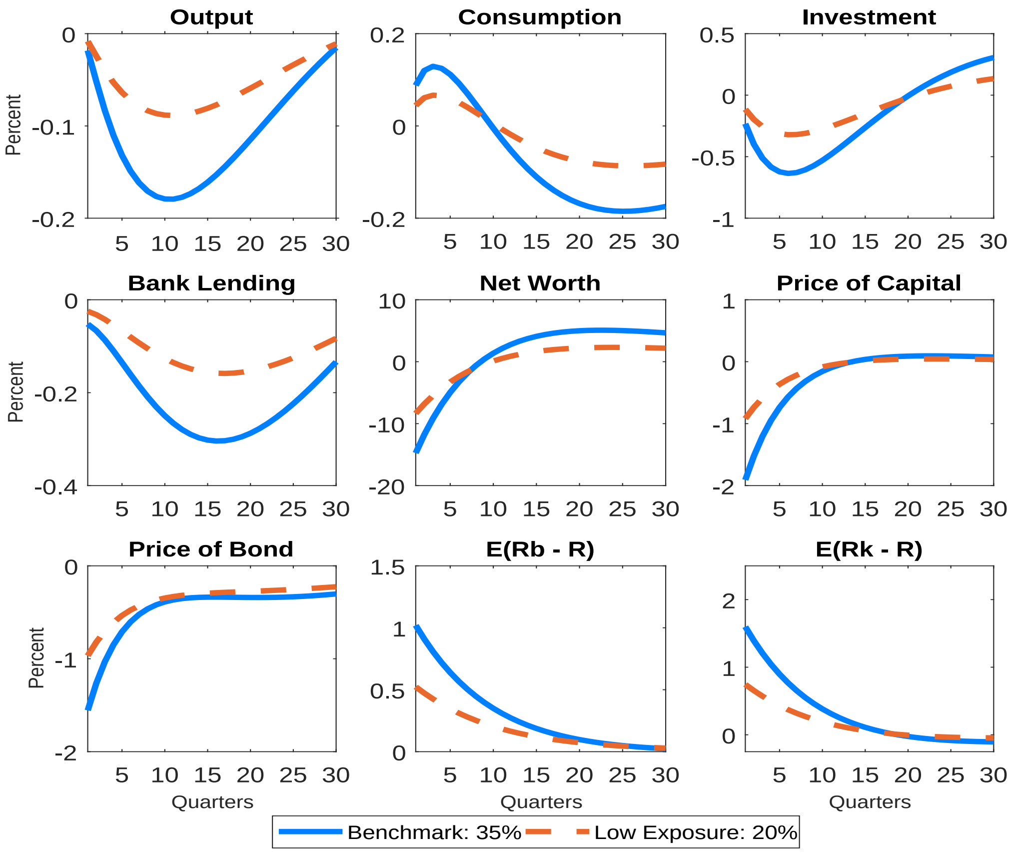

Figure 1.8: Impulse Responses from DSGE with Financial Intermediaries for Spain: Banks' Exposure to Government Bonds

Looking at Figure 1.8, we can observe the effects of the spread volatility shocks when banks have differing amounts of exposure to government bonds. We consider two illustrative cases – first when banks have high exposure to government debt (corresponding to banks holding 35% of total government bonds) and second when this exposure is less (20% in this case). It can be seen that compared with the benchmark case in which banks have 35% of total government debt, a lower exposure (20%) insulates banks from pernicious effects of volatility shocks. The decline in bank lending halves when banks have reduced exposure to sovereign debt. In similar

[16] Data from Merler and Pisani-Ferry (2012).

fashion, drop in output, investment and consumption is considerably less when bank exposure is comparatively limited. It is easy to see that after the volatility shocks, both the price of government bonds and price of capital falls more when banks have higher exposure and at the same time, the expected excess returns surge. With falling asset prices depressing banks' balance sheets, they demand a higher return as evident by uptick in excess returns. Taken together, these effects lead to a scenario where on the one hand, banks are constrained by their weaker balance sheets and on the other hand, they demand higher excess returns. This leads to a fall in bank lending to firms which then curtail their real economic activity.

Bank Leverage

Here, we discuss the role leverage plays in amplifying the impact of volatility shocks. As before, we consider two different scenarios to tease out the impact of volatility shocks in times of high and low leverage (see Figure 1.9).

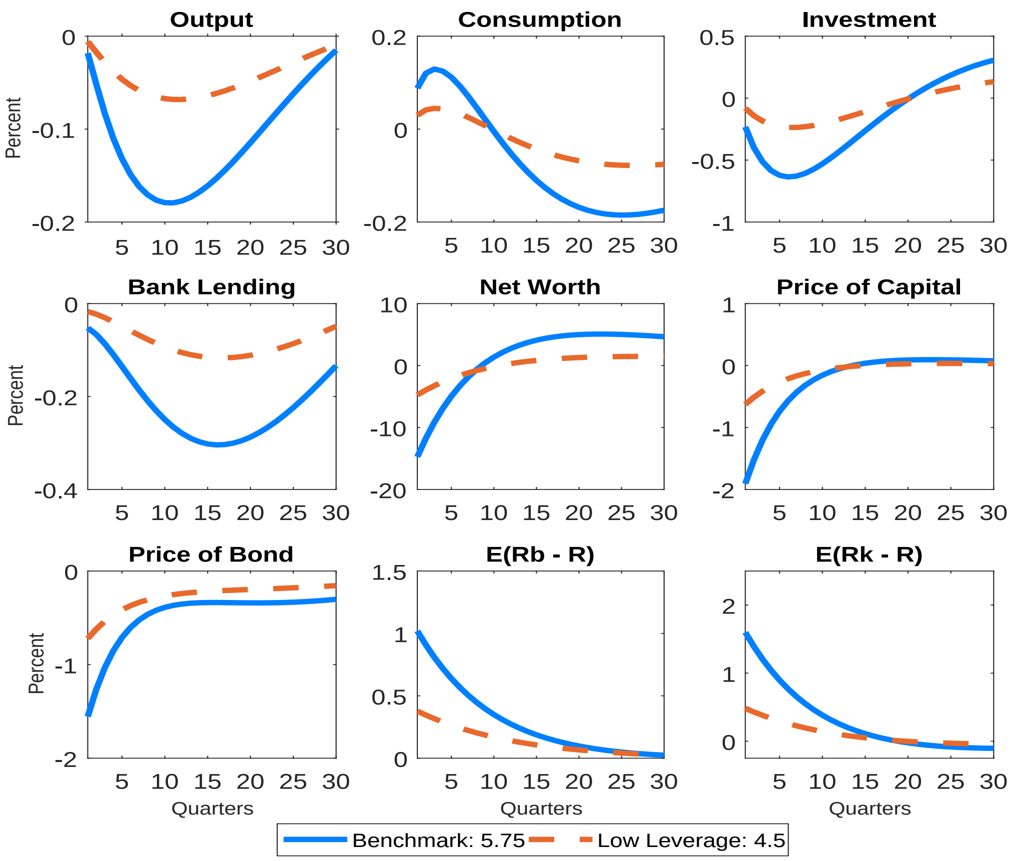

Figure 1.9: Impulse Responses from DSGE with Financial Intermediaries for Spain: Banks' Leverage

The leverage ratio of Spanish banks went up from 4.5 in 2007 to 5.75 in 2012.[17] This rise

[17] Leverage is computed as ratio of total domestic nonfinancial assets and equity. We use the reported "equity" on the banks' balance sheet as its measure. Our way of computing leverage follows Akinci and Queralto (2017). Data from Bank of Spain.

in leverage provides a natural setting to examine the possible implications of soaring leverage ratio in the context of spread volatility shocks. In the benchmark case when the leverage ratio is higher at 5.75, volatility shocks lead to a sharp and prolonged decline in bank lending, output, consumption and investment. In the low leverage case (lower ratio at 4.5), the effects of shocks are clearly moderated – the drop in real economic variables is not as much as in the benchmark case and we see a quicker rebound to their previous level. The driving force here is again the joint dynamics between fall in price of capital and price of bond (and hence, also in net worth) and hike in excess returns. When banks are more leveraged, drop in asset prices has stronger negative impact on their balance sheets. On the one hand, while it depresses their net worth, on the other hand, it raises their expected excess returns. The combination of these twin forces is a cutback in lending on their part which contributes to slowdown in real economic activity.

1.4 Conclusion

In this paper, we show that volatility shocks to spreads on government bonds issued by peripheral eurozone countries – Spain, Ireland, Portugal and Italy – was an important contributing factor in decline in bank lending to domestic nonfinancial firms and the wider slowdown in real economic activity. Particularly, we find that firms that borrowed from banks exposed to sovereign debt, became financially constrained and responded by reducing their investment and output. Consequently, unemployment rose and consumption dropped.

Further, we examine the mechanism behind contraction in bank lending and its impact on aggregate economic activity. We document that negative effects of volatility shocks for real economic activity can be attributed to a bank lending channel with (*i*) banks suffering a balance sheet impairment after a volatility shock, and (*ii*) resultant incentives of constrained banks to cut back their lending. In the wake of reduced bank credit, firms which meet their financing requirements from banks experience shortage of capital and curtail their investment and output. Our results also show that negative effects of volatility shocks on bank lending and subsequent economic activity are more pronounced when banks have higher exposure to sovereign debt or when they are more leveraged.

Our findings help develop a better understanding of how volatility shocks can have real economic consequences for the banking sector and the larger macroeconomy. We shed light on a new mechanism through which bank exposure to risky sovereign debt can result in negative economic outcomes. Our results indicate that bank recapitalization programs which tackle the problem of undercapitalized and weak banks can help address the stagnant bank lending in eurozone.

1.5 Appendix

1.5.1 Data definitions and sources

The following variables are used in the SVAR-SV exercise. All variables are on quarterly basis, unless stated otherwise. Data for Spain is mainly extracted from Datastream, whereas for Ireland, Portugal and Italy the source is Haver Analytics.[18] Data length varies among countries depending on availability.[19]

Spain (1990Q3-2017Q3)

- *Output* is seasonally adjusted real GDP, obtained from Oxford Economics. Mnemonic: ESXGDP$.D.
- *Consumption* is seasonally adjusted real private consumption, obtained from Oxford Economics. Mnemonic: ESXCPR$.D.
- *Investment* is seasonally adjusted real fixed investment, obtained from Oxford Economics. Mnemonic: ESXIFR$.D.
- *Bank lending* is nominal non-seasonally adjusted bank loans to NFIs, obtained from Datastream. It is seasonally adjusted using US Census Bureau's X-12 ARIMA. Mnemonic: ESBANKLPA.
- *Sovereign spread* is defined as return on one year Spanish government bonds net return on one year German government bonds, obtained from Datastream. Mnemonic: GVES03(CM01) for Spain and GVBD03(CM01) for Germany.
- *Unemployment* is harmonized unemployment rate (seasonally adjusted), obtained from St. Louis FRED. Mnemonic: LRHUTTTTESM156S.

Ireland (1997Q4-2017Q3)

- *Output* is seasonally adjusted real GDP, obtained from Haver Analytics. Mnemonic: IESNGDPC.
- *Consumption* is seasonally adjusted real private consumption, obtained from Haver Analytics. Mnemonic: IESNCPC.
- *Investment* is seasonally adjusted real gross fixed investment, obtained from Haver Analytics. Mnemonic: IESNFC.
- *Bank lending* is nominal non-seasonally adjusted bank loans to NFIs, obtained from European Central Bank – Statistical Data Warehouse.

[18] Nominal variables are divided by CPI. Mnemonic: ESNPC (Spain), IENPC (Ireland), PTNPC (Portugal) and ITNPC (Italy).

[19] Time spans after applying Q-o-Q growth rates.

Series Key: BSI.M.IE.N.A.A20.A.1.U6.2230.Z01.E. It is seasonally adjusted using US Census Bureau's X-12 ARIMA.

- *Sovereign spread* is defined as return on one year Irish government bonds net return on one year German government bonds. Data obtained from Datastream. Mnemonic: GVIR03(CM01) for Ireland and GVBD03(CM01) for Germany.
- *Unemployment* is harmonized unemployment rate (seasonally adjusted), obtained from St. Louis FRED. Mnemonic: LRHUTTTTIEM156S.

Portugal (1994Q4-2017Q3)

- *Output* is seasonally adjusted real GDP, obtained from Haver Analytics. Mnemonic: PTSGDPC.
- *Consumption* is seasonally adjusted real private consumption, obtained from Haver Analytics. Mnemonic: PTSNCC.
- *Investment* is seasonally adjusted real gross fixed investment, obtained from Haver Analytics. Mnemonic: PTSNIC.
- *Bank lending* is nominal seasonally adjusted total bank loans to NFIs, obtained from Haver Analytics. Mnemonic: PTNFCN.
- *Sovereign spread* is defined as return on one year Portuguese government bonds net return on one year German government bonds. Data obtained from Datastream. Mnemonic: GVPT03(CM01) for Portugal and GVBD03(CM01) for Germany.
- *Unemployment* is harmonized unemployment rate (seasonally adjusted), obtained from St. Louis FRED. Mnemonic: LRHUTTTTPTQ156S.

Italy (1998Q3-2017Q3)

- *Output* is seasonally adjusted real GDP, obtained from Haver Analytics. Mnemonic: ITSNGDPC.
- *Consumption* is seasonally adjusted real private consumption, obtained from Haver Analytics. Mnemonic: ITSNCHC.
- *Investment* is seasonally adjusted real gross fixed investment, obtained from Haver Analytics. Mnemonic: ITSNIC.
- *Bank lending* is nominal seasonally adjusted bank loans to NFIs, obtained from Haver Analytics. Mnemonic: ITNFDHT.
- *Sovereign spread* is defined as return on one year Italian government bonds net return on one year German government bonds. Data obtained from Datastream. Mnemonic: GVIT03(CM01) for Italy and GVBD03(CM01) for Germany.

- *Unemployment* is harmonized unemployment rate (seasonally adjusted), obtained from St. Louis FRED. Mnemonic: LRHUTTTTITM156S.

1.5.2 Sovereign Spread and Bank Lending

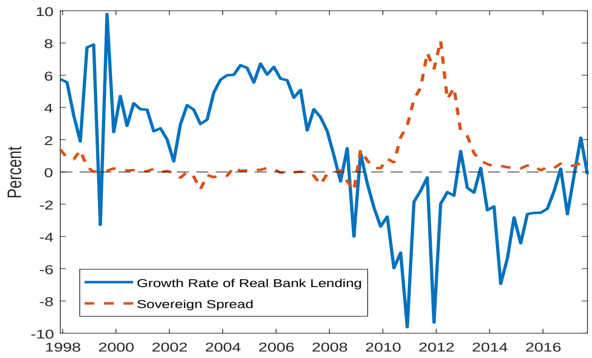

Figure 1.10: Sovereign Spread and Growth Rate of Bank Lending for Ireland

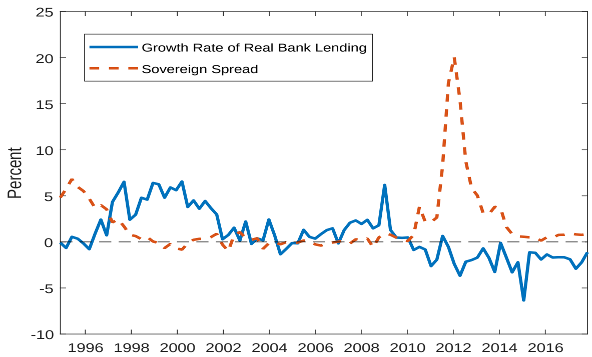

Figure 1.11: Sovereign Spread and Growth Rate of Bank Lending for Portugal

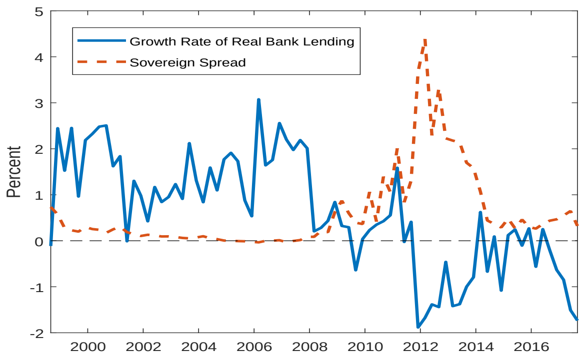

Figure 1.12: Sovereign Spread and Growth Rate of Bank Lending for Italy

1.5.3 Sovereign Spread Volatility Shock

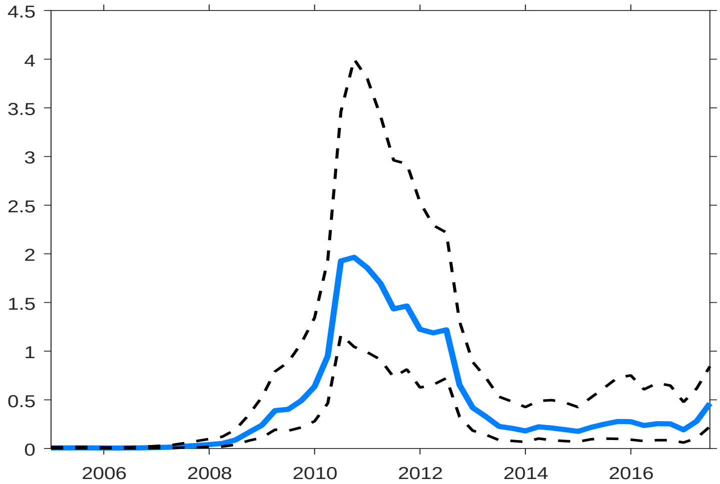

Figure 1.13: Estimated Sovereign Spread Volatility Shock During the Eurozone Debt Crisis, Spain

Note: Each entry shows the median and the 68% confidence bands.

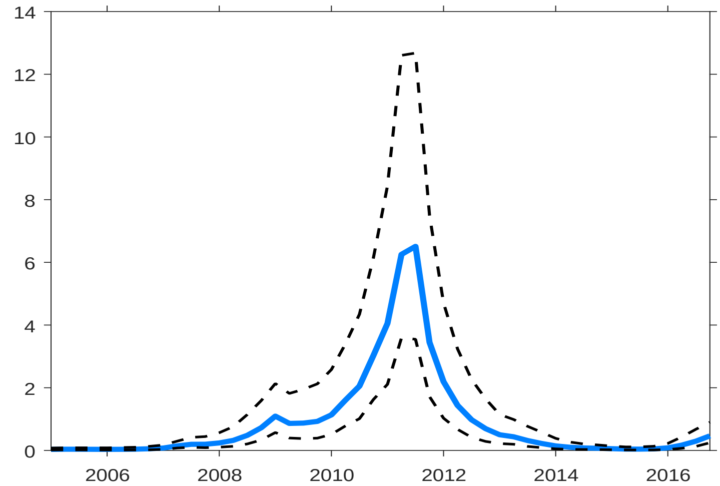

Figure 1.14: Estimated Sovereign Spread Volatility Shock During the Eurozone Debt Crisis, Ireland

Note: Each entry shows the median and the 68% confidence bands.

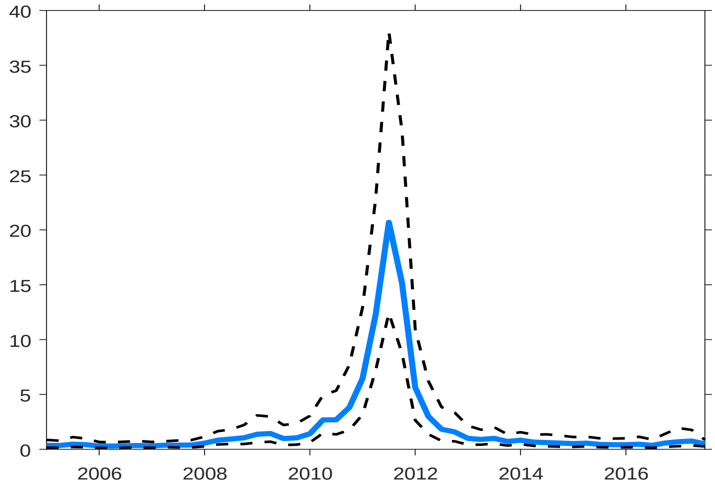

Figure 1.15: Estimated Sovereign Spread Volatility Shock During the Eurozone Debt Crisis, Portugal

Note: Each entry shows the median and the 68% confidence bands.

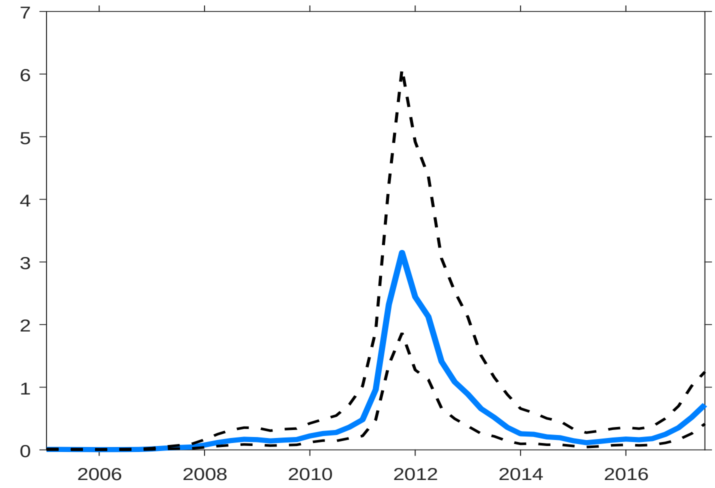

Figure 1.16: Estimated Sovereign Spread Volatility Shock During the Eurozone Debt Crisis, Italy

Note: Each entry shows the median and the 68% confidence bands.

1.5.4 SVAR-SV: Robustness Checks

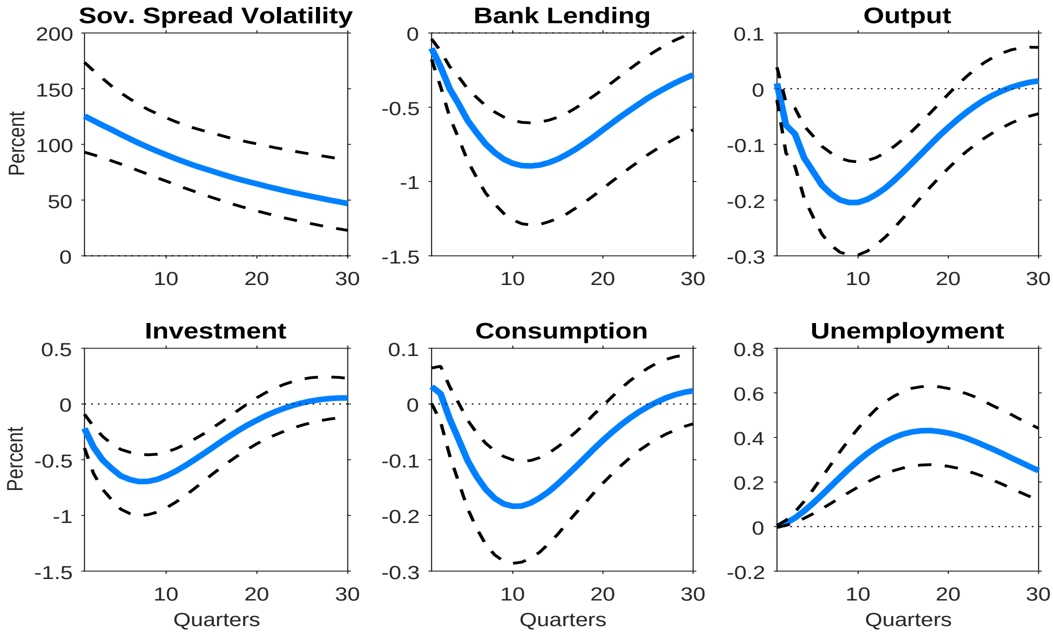

Figure 1.17: IRFs from Estimated SVAR-SV, Spain: Sovereign Spread Ordered Last
Note: Each entry shows the median and the 68% confidence bands.

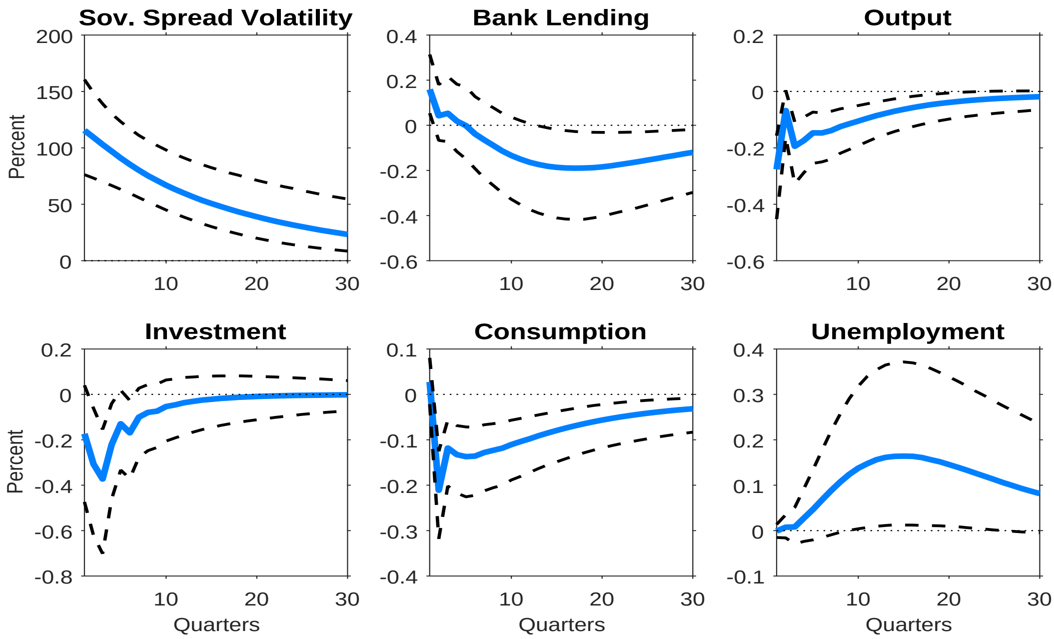

Figure 1.18: IRFs from Estimated SVAR-SV, Ireland: Sovereign Spread Ordered Last
Note: Each entry shows the median and the 68% confidence bands.

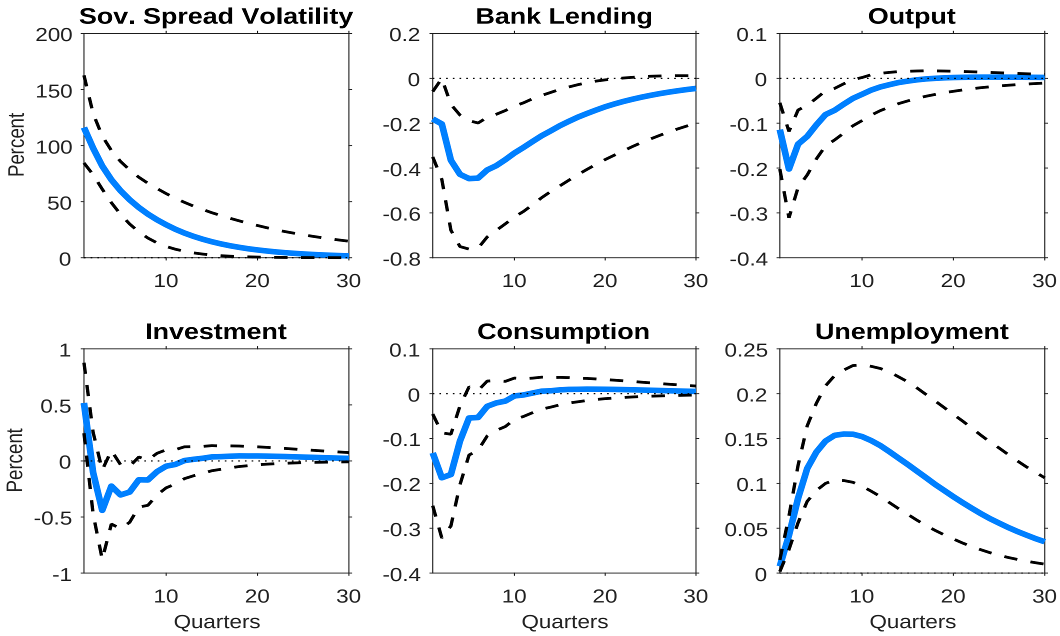

Figure 1.19: IRFs from Estimated SVAR-SV, Portugal: Sovereign Spread Ordered Last
Note: Each entry shows the median and the 68% confidence bands.

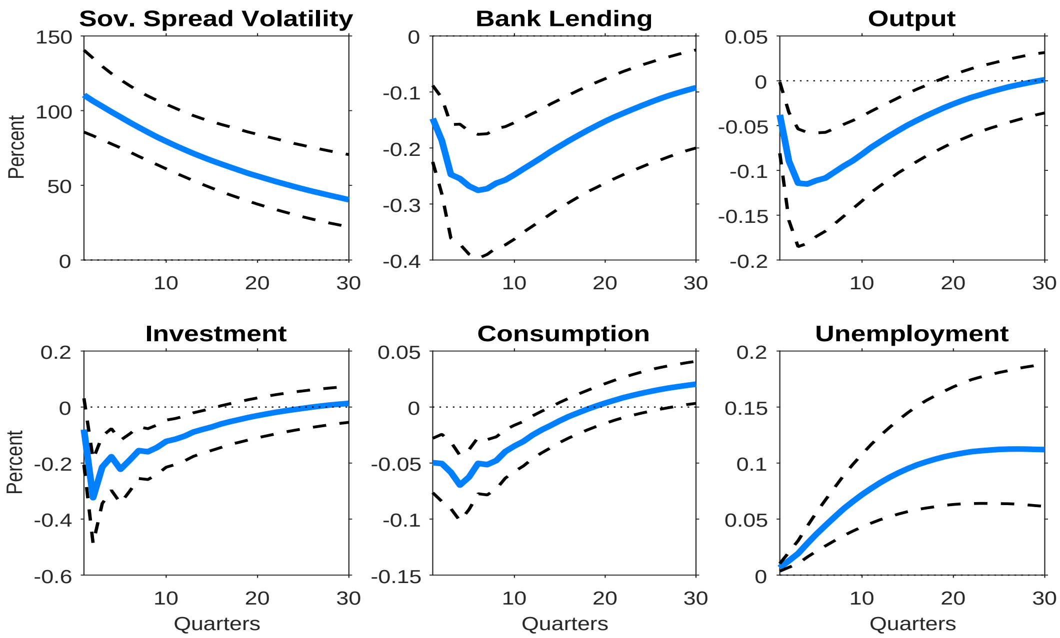

Figure 1.20: IRFs from Estimated SVAR-SV, Italy: Sovereign Spread Ordered Last
Note: Each entry shows the median and the 68% confidence bands.

Chapter 2

Financial Frictions in a Model with Fiscal Volatility Shocks

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Abstract

In this paper, I embed financial frictions in a model of fiscal volatility shocks. Fernández-Villaverde et al. (2015) show that volatility shocks to fiscal instruments, particularly tax rate on capital income, can have significantly detrimental impact on overall economic activity. This paper shows how these effects change when there are financial frictions. The results in this paper provide lower bounds to effects of fiscal volatility shocks.

2.1 Introduction

There has been considerable disagreements at various levels of US government regarding its fiscal policy. There is a common perception that this increased uncertainty about fiscal policy – both in terms of mix of fiscal instruments and timing of their use – has resulted in negative effects on aggregate economic activity.

Fernández-Villaverde et al. (2015) (FGKR now on) look at real effects of this increased uncertainty surrounding fiscal policy and find that volatility shocks to fiscal policy in the US carried negative effects on investment, output, consumption and labor. They estimate a VAR along the lines of Christiano, Eichenbaum and Evans (2005) using US data and study how the economy responds to a positive two standard deviation innovation to fiscal volatility shock. They estimate shocks to fiscal volatility using particle filter (more details on this in the next section) and combine it with data on output per capita, consumption per capita, investment per capita, real wages, hours per capita, markups, GDP deflator and the quartely average of the federal funds rate. They find that after a volatility shock, markups rise while output, consumpion, investment, hours, prices, the federal funds rate and the real wage fall significantly.

They later build a New Keynesian model a la Christiano, Eichenbaum and Evans (2005) and show that through a rise in markup, volatility shocks to capital income lead to a drop in investment. At the same time, there is a prolonged decline in output, consumption and real wages.

In this paper, I study the effects of fiscal volatility shocks in presence of financial frictions. There is There is considerable evidence (see for instance, figure 2.1) that period of heightened uncertainty are also marked by elevated levels of financial frictions. Hence, ignoring the potential effects of financial constraints is likely to underestimate the impact of volatility shocks. My results which take into account this fact, therefore provide a lower bound to the effects of fiscal volatility shocks.

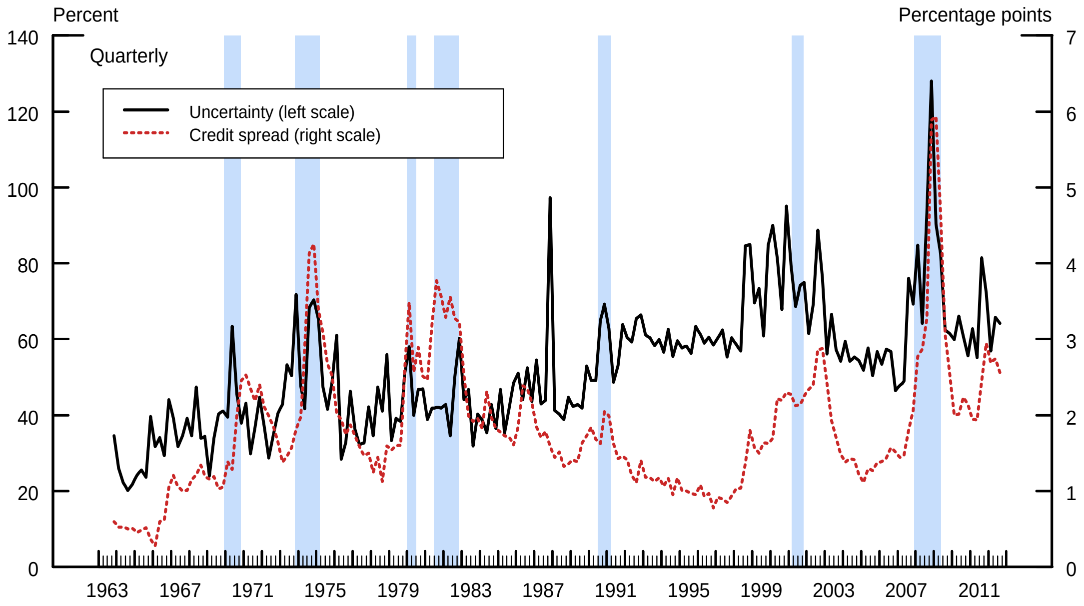

Figure 2.1: Credit Spreads and Uncertainty
Source: Gilchrist, Sim and Zakrajšek (2014). Sample period: 1963:Q4â2012:Q3. The solid line depicts the estimate of idiosyncratic uncertainty (in annualized percent) based on firm-level equity returns. The dotted line depicts the spread between the 10-year yield on BBB-rated nonfinancial corporate bonds and the 10-year Treasury yield. The shaded vertical bars denote the NBER-dated recessions.

This is the first paper that examines impact of fiscal volatility shocks on economic aggregates in presence of financial frictions. This paper features fiscal volatility shocks of Fernández-Villaverde et al. (2015) and uses the framework of Christiano, Motto and Rostagno (2014) to introduce financial frictions in the model. It then investigates how presence of financial frictions affect the macroeconomic implications of fiscal volatility shocks.

Related Literature

This paper is related to several stands of literature. First, it is connected with rapidly developing literature of macroeconomic effects of uncertainty shocks. Since seminal paper of Bloom (2009), many other papers have explored this topic, including Bloom et al. (2012), Born and Pfeifer (2014) and Fernández-Villaverde et al. (2011), to cite just a few papers.

On the other hand, this work is related with financial frictions, specifically putting it together with uncertainty shocks. There have been a few papers which investigated impact of uncertainty shocks under financial frictions. Notable contributions include, among others, Gilchrist, Sim and Zakrajšek (2014), Christiano, Motto and Rostagno (2014), Balke, Martínez-García and Zeng (2011) and Cesa-Bianchi and Corugedo (2014)[1].

2.2 Model

I embed financial frictions into a business cycle model. To keep the analysis comparable, I keep the model as close to Fernández-Villaverde et al. (2015) as possible. I introduce financial frictions as in Christiano, Motto and Rostagno (2014). As in Fernández-Villaverde et al. (2015), I maintain the distinction between fiscal shocks and fiscal volatility shocks. Uncertainty about permanent changes in fiscal policy has important effects (Bi, Leeper and Leith (2013)). The goal here is to study response of economy to temporary and and unexpected increase in fiscal policy uncertainty.

2.2.1 Fiscal Rules

The fiscal rules in this paper model the evolution of four policy instruments: government spending as a share of output, $\tilde{g}_t$, and tax rates on labor income, $\tau_{l,t}$, on capital income, $\tau_{k,t}$ and on personal consumption expenditure, $\tau_{c,t}$. Their specification is taken from Fernández-Villaverde et al. (2015) and reproduced here for the sake of completeness. For each instrument, law of motion is given as

$$x_t - x = \rho_x(x_{t-1} - x) + \phi_{x,y}\tilde{y}_{t-1} + \phi_{x,b}(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}) + exp(\sigma_{x,t})\xi_{x,t}, \qquad \xi \sim N(0,1) \qquad (2.1)$$

for $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$ where $\tilde{g}$ is the mean government spending as a share of output and τ_x is the mean of tax rate. Above, $\tilde{y}_{t-1}$ is lagged detrended log output, b_t is the public debt (with $\frac{b}{y}$ being the mean debt-to-output ratio), and y_t is output. Equation 1 allows for two feedbacks: one from the state of business cycle ($\phi_{\tau_x,y} > 0$ and $\phi_{\tilde{g},y} < 0$) and another from the debt-to-output ratio ($\phi_{\tau_x,b} > 0$ and $\phi_{\tilde{g},b} < 0$).

[1] Gilchrist, Sim and Zakrajšek (2014) shows, using a standard bond contracting framework that cost of capital increases. driving down investment, as a result of uncertainty shocks. Christiano, Motto and Rostagno (2014) build a DSGE model incorporating the financial accelerator mechanism of Bernanke, Gertler and Gilchrist (1999) and report that risk shocks and are important drivers of US business cycles. Their analysis focuses on idiosyncratic uncertainty shocks. Balke, Martínez-García and Zeng (2011) use a model with agency costs and shows that contractionary effects of financial accelerator are greater with price stickiness. Similar effects on investment, output and consumption are found under credit frictions by Cesa-Bianchi and Corugedo (2014)

The equation incorporates time-varying volatility in the form of stochastic volatility. Namely, the log of the standard deviation, $\sigma_{x,t}$, of the innovation to each policy instrument is random, and not constant, as traditionally assumed. $\sigma_{x,t}$ is modeled as

$$\sigma_{x,t} = (1-\rho_{\sigma_x})\sigma_x + \rho_{\sigma_x}\sigma_{x,t-1} + (1-\rho_{\sigma_x})^{\frac{1}{2}}\eta_x u_{x,t}, \qquad u_{x,t} \sim N(0,1) \tag{2.2}$$

In this formulation, two independent innovations affect the fiscal instrument x. The first innovation, $\xi_{x,t}$, changes the instrument itself, while the second innovation, $u_{x,t}$, determines the spread of values for the fiscal instrument. $\xi_{x,t}$ can be called an innovation to the fiscal shock to the instrument x and $\sigma_{x,t}$ a fiscal volatility shock to instrument x with innovation $u_{x,t}$.

The $\xi_{x,t}s$ are not the observed changes in the fiscal instruments, but the deviations of the data with respect to the historical response to the regressors in equation 1. The $\xi_{x,t}s$ capture both explicit changes in legislation and a wide range of fiscal actions whenever government behavior deviates from what could have been expected given the past values of the fiscal instruments, the stage of the business cycle, and the level of government debt. There may be nonzero $\xi_{x,t}s$ even in the absence of new legislation. Examples include changes in effective tax rate if policymakers, through legislation inaction, allow fro bracket creep in inflationary times, or for changes in effective capital income tax rates in booming stock markets.

The parameter σ_x determines the average standard deviation of an innovation to the fiscal shock to instrument x, η_x is the unconditional standard deviation of an innovation of the fiscal volatility shock to instrument x, and ρ_{σ_x} controls the persistence of the shock. A value of $\sigma_{\tau_k,t} > \sigma_{\tau_k}$, for instance, implies greater than usual uncertainty about the future path of capital tax rates. variations of $\sigma_{x,t}$ over time, in turn, will depend on η_x and ρ_{σ_x}. Stochastic volatility intuitively models such changes while introducing only two parameters for each instrument (η_x and ρ_{σ_x}).

The rest of this section introduces a business cycle model. Fernández-Villaverde et al. (2015) include fiscal policy in an NK model as in Christiano, Eichenbaum and Evans (2005) since it fits many features of US business cycle. I keep their specification of households' utility function since this features government expenses which play an important role in this paper. I depart from their modeling framework, however, by assuming existence of entrepreneurs in each household[2]. Their model contains a representative household and does not feature entrepreneurs.

2.2.2 Households

There is a large number of identical and competitive households. Each household supplies every type of differentiated labor $l_{j,t}, j \in [0,1]$. By assuming each household contains every type of differentiated labor, I abstract from distributional issues.

[2]This is the central assumption in the model. Since the focus of this paper is examining impact of unanticipated and temporary changes in fiscal instruments (government spending and taxes on labor income, capital income and personal consumption expenditure), it is crucial that households contain both simple consumers as well as entrepreneurs so that their utility maximization problem contains a budget constraint that includes investment, capital, returns on capital and the corresponding taxes. For this reason, I do not assume a separate class of 'entrepreneurs' because in that case, budget constraint of households will have to change and here, I want to keep it as it is.

The preferences of the representative household are separable in consumption c_t, government expenditure g_t and labor:

$$E_0 \sum_{t=0}^{\infty} \beta^t d_t \Big\{ \frac{(c_t - b_h c_{t-1})^{1-\varphi}}{1-\varphi} + v(g_t) - \psi A_t^{1-\varphi} \int_0^1 \frac{l_{j,t}^{1+\nu}}{1+\nu} dj \Big\} \tag{2.3}$$

E_0 is the conditional expectation operator, β is the discount factor, ν is the inverse of the Frisch elasticity of labor supply, b_h governs habit formation, $g_t = \tilde{g}_t y_t$ is government spending and $v(\cdot)$ is an increasing, concave and bounded from above function. Preferences are subject to a preference shock[3] d_t that follows log $d_t = \rho_d \log d_{t-1} + \sigma_d \epsilon_{dt}$, where $\epsilon_{dt} \sim N(0,1)$ and to a labor-augmenting unit root productivity shock A_t that is introduced below. Preferences of the households are subject to shocks to allow the model to capture fluctuations in interest rates not accounted for variations in consumption. The presence of A_t in the utility function ensures existence of a balanced growth path.

$$\underbrace{(1+\tau_{c,t})c_t}_{\text{consumption}} + \underbrace{b_t}_{\text{government bonds}} + \underbrace{b_t^{FI}}_{\text{FI bonds}} + \underbrace{\Omega_t}_{\text{lump-sum taxes}} + \underbrace{\int_0^1 AC_{j,t}^w dj}_{\text{wage adjustment costs}} + \underbrace{i_t}_{\text{investment}}$$
$$= \underbrace{(1-\tau_{l,t}) \int_0^1 w_{j,t} l_{j,t} dj}_{\text{wages of differentiated labor}} + \underbrace{(1-\tau_{k,t}) r_{k,t} u_t k_{t-1}}_{\text{return on capital}} + \underbrace{\tau_{k,t} \delta k_{t-1}^b}_{\text{depreciation allowance}} + \underbrace{b_{t-1} \frac{R_{t-1}}{\pi_t}}_{\text{return from government bonds}}$$
$$+ \underbrace{b_{t-1}^{FI} \frac{R_{t-1}^{FI}}{\pi_t}}_{\text{return from FI bonds}} + \underbrace{F_t}_{\text{profits of the firms and transfers from entrepreneurs}} \tag{2.4}$$

The above equation shows the household's budget constraint. The household invests, i_t, in capital and buys government bonds, B_t. Besides, the household also makes deposits with financial intermediaries, B_t^{FI}, at a competitively determined interest rate, R_t^{FI}. On their investment, i_t, they get a rental of $r_{k,t}$ which is affected by the utilization rate of capital u_t. The real values of government bonds and deposits with financial intermediaries at the end of the period is $b_t = \frac{B_t}{P_t}$ and $b_t^{FI} = \frac{B_t^{FI}}{P_t}$ respectively, where P_t is the price level. The real values of the government bonds and deposits with financial intermediaries at the start of period t is $b_{t-1}\frac{R_{t-1}}{\pi_t}$ and $b_{t-1}^{FI}\frac{R_{t-1}^{FI}}{\pi_t}$, where $\pi_t = \frac{P_t}{P_{t-1}}$ is inflation between $t-1$ and t. The household pays consumption taxes $\tau_{c,t}$, labor income taxes $\tau_{l,t}$, capital income taxes $\tau_{k,t}$ and lump-sum taxes Ω_t. The capital tax is levied on capital income which is given by the product of amount of capital owned by household k_{t-1}, the rate of utilization of capital u_t and the rental rate of capital $r_{k,t}$. There is a depreciation allowance for the book value of the capital k_{t-1}^b. The household receives the profits of the firms in the economy and transfers from entrepreneurs F_t. The real wage for labor of type $j, w_{j,t}$ is subject to an adjustment cost $AC_{j,t}^w = \frac{\phi_w}{2}(\frac{w_{j,t}}{w_{j,t-1}} - g_A)^2 y_t$, scaled by aggregate

[3] This can be used as a demand shock since an increase in d_t can induce households to increase consumption and work less for no technological reason. This can be used to simulate an episode of a large decline in household demand which can generate a zero lower bound scenario (Bundick and Smith (2016)).

output y_t. Adjustments costs have been scaled to avoid them becoming asymptotically small as GDP grows. Here g_A is the steady-state growth rate of the economy to be defined shortly.

Following Erceg, Henderson and Levin (2000), a perfectly competitive labor packer aggregates the different types of labor, $l_{j,t}$ into homogeneous labor l_t with the production function $l_t = (\int_0^1 l_{j,t}^{\frac{\epsilon_w - 1}{\epsilon_w}} dj)^{\frac{\epsilon_w}{\epsilon_w - 1}}$ where ϵ_w is the elasticity of substitution among labor types. The homogeneous labor is rented by the intermediate goods producers at real wage w_t. The labor packer takes the wages $w_{j,t}$ and w_t as given. The optimal behavior of labor packer implies a demand for each type of labor: $l_{j,t} = (\frac{w_{j,t}}{w_t})^{-\epsilon_w} l_t$. By a zero-profit condition, $w_t = (\int_0^1 w_{j,t}^{1-\epsilon_w})^{\frac{1}{1-\epsilon_w}}$.

A geometric depreciation schedule is assumed under which in each period a share δ of the remaining book value of capital is tax-deductible. Thus, the depreciation allowance in period t is given by $\delta k_{t-1}^b \tau_{k,t}$ where k_t^b is the book value of the capital stock the evolves according to $k_t^b = (1-\delta)k_{t-1}^b + i_t$.

In a symmetric equilibrium, the first-order conditions of the household problem of maximizing expected utility with respect to $c_t, w_{j,t}, j \in (0,1), b_t, b_t^{FI}, u_t, k_t, k_t^b$ and i_t are:

$$\frac{d_t}{(c_t - b_h c_{t-1})^{\varphi}} - E_t \frac{b_h \beta d_{t+1}}{(c_{t+1} - b_h c_t)^{\varphi}} = \lambda_t (1 + \tau_{c,t}) \tag{2.5}$$

$$\begin{aligned} \phi_w y_t \left(\frac{w_t}{w_{t-1}} - g_A \right) \frac{w_t}{w_{t-1}} = E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \phi_w y_{t+1} \left(\frac{w_{t+1}}{w_t} - g_A \right) \frac{w_{t+1}}{w_t} \right\} + \\ \left[A_t^{1-\varphi} \frac{d-t}{\lambda_t} \psi \epsilon_w (l_t^d)^{1+\vartheta} - (\epsilon_w - 1)(1 - \tau_{l,t}) w_t l_t^d \right] \end{aligned} \tag{2.6}$$

$$\lambda_t = \beta E_t \left\{ \lambda_{t+1} \frac{R_t}{\Pi_{t+1}} \right\} \tag{2.7}$$

$$\lambda_t = \beta E_t \left\{ \lambda_{t+1} \frac{R_t^{FI}}{\Pi_{t+1}} \right\} \tag{2.8}$$

$$r_{k,t} \left(1 - \tau_{k,t}\right) = q_t \delta' \left[u_t\right] \tag{2.9}$$

$$q_t = E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \delta[u_{t+1}]) q_{t+1} + (1 - \tau_{k,t+1}) r_{k,t+1} u_{t+1} \right] \right\} \tag{2.10}$$

$$q_t^b = E_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \delta) q_{t+1}^b + \delta \tau_{k,t+1} \right] \right\} \tag{2.11}$$

$$1 = q_t \left(1 - S\left[\frac{i_t}{I_{t-1}} \right] - S'\left[\frac{i_t}{i_{t-1}} \right] \frac{i_t}{i_{t-1}} \right) + \beta E_t \left\{ q_{t+1} \frac{\lambda_{t+1}}{\lambda_t} S'\left[\frac{i_{t+1}}{i_t} \right] \left(\frac{i_{t+1}}{i_t} \right)^2 \right\} + q_t^b \tag{2.12}$$

2.2.3 Retailers

There is a a continuum of retailers indexed by $i \in [0,1]$ in the economy. They purchase intermediate goods at price P_t^w and produce differentiated retail goods $Y_t(i)$. Final goods Y_t used for consumption and investment are CES aggregates of retail goods such that

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{2.13}$$

where ϵ is the elasticity of substitution among retail goods. The demand curve for each retail good $Y_t(i)$ is thus given by

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t. \tag{2.14}$$

Retailers face Rotemberg adjustment costs in charging prices of the form $\frac{\Omega_P}{2}\left(\frac{P_t(i)}{P_{t-1}(i)}\frac{1}{\pi}-1\right)^2 Y_t$, such that price changes in excess of steady-state inflation rates are costly. The retail goods firms i maximizes

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left(\frac{P_{t+j}(i) - P_{t+j}^w}{P_{t+j}} Y_{t+j}(i) - \frac{\Omega_P}{2}\left(\frac{P_{t+j}(i)}{P_{t+j-1}(i)}\frac{1}{\pi} - 1\right)^2 Y_{t+j}\right) \tag{2.15}$$

subject to the demand function 2.14. The first order condition is

$$\frac{1}{x_t} = \frac{\epsilon-1}{\epsilon} + \frac{\Omega_P}{\epsilon}\left(\frac{\pi_t}{\pi}-1\right)\frac{\pi_t}{\pi} - \beta\frac{\Omega_P}{\epsilon}\mathbb{E}_t\frac{C_t}{C_{t+1}}\left(\frac{\pi_{t+1}}{\pi}-1\right)\frac{\pi_{t+1}}{\pi}\frac{Y_{t+1}}{Y_t}, \tag{2.16}$$

where $x_t = \frac{P_t}{P_t^w}$. Equation 2.16 represents the New Keynesian Phillips Curve (NKPC) under Rotemberg pricing. Monopoly profits are transferred to households and are given by

$$F_t^R = Y_t - \frac{1}{x_t}Y_t - \frac{\Omega_P}{2}\left(\frac{\pi_t}{\pi}-1\right)^2 Y_t. \tag{2.17}$$

2.2.4 Intermediate Goods Firms

A continuum of intermediate goods firms indexed by j use capital and labor as inputs for production. Each firm j faces an idiosyncratic productivity shock ω_t^j that is i.i.d. drawn from a log normal distribution, $F(\cdot)$, with a mean of 1. Consequently, each firm's output can vary contingent on the realization of ω_t^j,

$$Y_t^j = \omega_t^j (K_{t-1}^j)^\alpha \left(A_t (l_t^{e,j})^{1-\theta} (l_t^j)^\theta\right)^{1-\alpha}, \tag{2.18}$$

where A_t represents the aggregate productivity shock. $l_t^{e,j}$ is the demand for managerial labor and l_t^j is the demand for household labor.

Intermediate firms face a working capital constraint. They have to pay for wages and capital rents before production takes place. Following the literature, I assume that each firm starts with the same level of beginning-of-period capital, k_{t-1}. Therefore, all intermediate goods firms face the same ex ante cost minimization problem as such:

$$\min \quad w_t l_t + r_{k,t} k_{t-1} + w_t^e l_t^e \tag{2.19}$$

$$\text{such that} \quad Y_t^j = \omega_t^j (K_{t-1}^j)^\alpha \left(A_t (l_t^{e,j})^{1-\theta} (l_t^j)^\theta \right)^{1-\alpha}. \tag{2.20}$$

Assuming ν_t is the Lagrangian multiplier associated with the production function, the optimality conditions are

$$w_t = \nu_t (1-\alpha)\theta \frac{Y_t}{l_t} \tag{2.21}$$

$$w_t^e = \nu_t (1-\alpha)(1-\theta) \frac{Y_t}{l_t^e} \tag{2.22}$$

$$r_t^k = \nu_t \alpha \frac{Y_t}{k_{t-1}} \tag{2.23}$$

In a model without working capital constraint, the competitive market drives profits to zero for intermediate goods firms, and therefore $\nu_t = 1/x_t$. In this model, however, the working capital constraint renders a wedge between ν_t and $1/x_t$. Combining 2.21, 2.22 and 2.23, we have

$$\frac{1}{\nu_t} = \left(\frac{1-\alpha}{r_t^k} \right)^{1-\alpha} \left(A_t \left(\frac{\alpha(1-\theta)}{w_t^e} \right)^{1-\theta} \left(\frac{\alpha\theta}{w_t} \right)^\theta \right)^\alpha. \tag{2.24}$$

To finance the expenses on wages and capital rents, firms resort to their own beginning-of-period net worth, N_{t-1}, which is assumed to be the same across firms, and external debt. Again, all firms would borrow the same amount of debt, B_t, for the given state of the economy, as the idiosyncratic productivity shock is i.i.d.:

$$\frac{N_{t-1} + B_t}{P_t} = w_t l_t + w_t^e l_t^e + r_t^k k_{t-1}. \tag{2.25}$$

Therefore,

$$\frac{Y_t}{x_t} = \tilde{A}_t \frac{N_{t-1} + B_t}{P_t}, \tag{2.26}$$

where $\tilde{A}_t$ is the overall return on working capital, given by

$$\tilde{A}_t = \frac{1}{x_t} \left(\frac{1-\alpha}{r_t^k} \right)^{1-\alpha} \left(A_t \left(\frac{\alpha(1-\theta)}{w_t^e} \right)^{1-\theta} \left(\frac{\alpha\theta}{w_t} \right)^\theta \right)^\alpha. \tag{2.27}$$

2.2.5 Financial Intermediaries

At the beginning of each period, a risk-neutral financial intermediary (FI) obtains households deposits, D_t, at the interest rate, R_t. It lends to intermediate goods firms, which choose the level of debt prior to the realization of idiosyncratic firm-specific productivity shocks and charges a rate of Z_t. The optimal contract is then characterized by a threshold on idiosyncratic productivity, $\bar{\omega}_t$, such that the intermediate goods producer with the cutoff productivity is just able to repay the external debt B_t:

$$\bar{Y}_t P_t^w = Z_t B_t, \tag{2.28}$$

where $\bar{Y}_t$ is the firm production with the cutoff idiosyncratic productivity,

$$\bar{Y}_t = \bar{\omega}_t^j (k_{t-1}^j)^{1-\alpha} \left(A_t (l_t^e)^{1-\theta} (l_t)^\theta \right)^\alpha , \tag{2.29}$$

It is worth pointing out that $\bar{y}_t = \bar{\omega}_t y_t$, as all intermediate goods firms face the same ex ante cost minimization problem and make the same resource allocation decisions. Working capital constraint of the intermediate goods firms is given by

$$\tilde{A}_t (N_{t-1} + B_t) = Y_t P_t^w . \tag{2.30}$$

We thus have

$$\bar{\omega}_t = \frac{Z_t B_t}{\tilde{A}_t (N_{t-1} + B_t)} \tag{2.31}$$

When $\omega_t \geq \bar{\omega}_t$, the firm repays the loan and FI receives the payoff of $Z_t B_t$. When $\omega_t < \bar{\omega}_t$, the firm cannot pay the contractual return and has to default. In this case, the FI pays a monitoring cost, defined as a fraction μ of the firm's realized total revenue, to observe the realized idiosyncratic productivity shock and collect the firm's production. Overall, the expected nominal income for the lender is given by

$$\begin{aligned}
&[1 - F(\bar{\omega}_t)]\, Z_t B_t + (1-\mu) \int_0^{\bar{\omega}_t} \tilde{A}_t \omega_t (N_{t-1} + B_t) F(\omega) \\
&= [1 - F(\bar{\omega}_t)] \left[\bar{\omega}_t \tilde{A}_t (N_{t-1} + B_t) + (1-\mu) \int_0^{\bar{\omega}_t} \tilde{A}_t \omega_t (N_{t-1} + B_t) F(\omega) \right] \\
&= \tilde{A}_t (N_{t-1} + B_t) \underbrace{\left[\{1 - F(\bar{\omega}_t)\} \bar{\omega}_t + (1-\mu) \int_0^{\bar{\omega}_t} \omega F(\omega) \right]}_{g(\bar{\omega}_t)} .
\end{aligned} \tag{2.32}$$

As a result, the FI would lend to firms if the following participation constraint holds:

$$\tilde{A}_t (N_{t-1} + B_t) g(\bar{\omega}_t) \geq R_t B_t \tag{2.33}$$

which illustrates FI' supply of debt. Given the participation constraint, firms choose $\bar{\omega}_t$ and B_t to maximize their expected income which is

$$\tilde{A}_t (N_{t-1} + B_t) \underbrace{\left(\int_{\bar{\omega}_t}^{\infty} \omega F(\omega) - (1 - F(\bar{\omega}_t)) \bar{\omega}_t \right)}_{f(\bar{\omega}_t)}, \tag{2.34}$$

where $\tilde{A}_t f(\bar{\omega}_t)$ can be interpreted as firms' expected return on their total asset $N_{t-1} + B_t$. The following first-order condition characterizes the optimal contract

$$\frac{N_{t-1}}{N_{t-1} + B_t} = -\frac{g'(\bar{\omega}_t)}{f'(\bar{\omega}_t)} \frac{\tilde{A}_t f(\bar{\omega}_t)}{R_t}, \tag{2.35}$$

which illustrates firm's demand for external debt. Additionally, I follow the literature and assume that only a share ζ of intermediate goods firms survive at the end of each period. This assumption ensures that firms' won't accumulate enough net worth such that they do not need to resort to external debt for financing. Therefore, end-of-period aggregate net worth, N_t depends on profits from surviving firms and managerial labor income which can be described as follows

$$N_t = \zeta \tilde{A}_t (N_{t-1} + B_t) f(\bar{\omega}_t) + P_t w_t^e l_t^e. \tag{2.36}$$

The net worth of firms that don't survive, $(1-\zeta)\tilde{A}_t(N_{t-1}+B_t)f(\bar{\omega}_t)$, is transferred to households in a lump-sum way.

Loan Demand and Supply with Credit Shocks

In a competitive market for financial intermediaries, their zero profit condition implies that the following constraint has to hold for any loan contract

$$\tilde{A}_t (N_{t-1} + B_t) g(\bar{\omega}_t) = R_t B_t. \tag{2.37}$$

Defining the leverage ratio as $L_t = \frac{N_{t-1}+B_t}{N_{t-1}}$, the loan supply constraint becomes

$$L_t = \frac{1}{1 - \frac{\tilde{A}_t}{R_t} g(\bar{\omega}_t)}. \tag{2.38}$$

As $g(\bar{\omega}_t)$ is an increasing function of $\bar{\omega}_t$, a higher productivity cutoff raises the return on working capital relative to deposit rate which raises the FI's willingness to lend and therefore the leverage ratio.

Given the FI participation constraint, on the other hand, intermediate goods firms maximize their expected income given by

$$\tilde{A}_t (N_{t-1} + B_t) f(\bar{\omega}_t) = N_{t-1} \underbrace{\frac{1}{1 - \dfrac{\tilde{A}_t}{R_t} g(\bar{\omega}_t)}}_{\text{leverage}} \underbrace{\tilde{A}_t f(\bar{\omega}_t)}_{\text{firms' expected return}}. \tag{2.39}$$

For the given return on working capital, $\tilde{A}_t$, and existing net worth, N_{t-1}, firms' expected income depends on the leverage ratio and the expected return on their assets, both of which depend on productivity cutoff, $\bar{\omega}_t$. Moreover, $f'(\cdot) < 0$ and $g'(\cdot) > 0$ imply that a higher cutoff imposes trade-offs for firms – it raises the leverage but reduces the expected return. Therefore, firms choose $\bar{\omega}_t$ optimally to balance the trade-offs and maximize the overall income. Its first order condition becomes

$$\underbrace{\frac{\frac{\tilde{A}_t}{R_t}g'(\bar{\omega}_t)}{1-\frac{\tilde{A}_t}{R_t}g(\bar{\omega}_t)}}_{\text{elasticity of leverage w.r.t.}\bar{\omega}_t} = \underbrace{-\frac{f'(\bar{\omega}_t)}{f(\bar{\omega}_t)}}_{\text{elasticity of firms' expected return w.r.t}\bar{\omega}_t} \tag{2.40}$$

2.2.6 The Government

The model is closed by a description of monetary and fiscal authorities. The monetary authority sets the nominal interest rate according to a Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\phi_R} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\phi_R)\gamma_\Pi} \left(\frac{y_t}{yA_t}\right)^{(1-\phi_R)\gamma_y} exp(\sigma_m \xi_t) \tag{2.41}$$

The parameter $\phi_R \in [0,1)$ generates interest-rate smoothing. The parameters $\gamma_\Pi > 0$ and $\gamma_y \geq 0$ control the responses to deviations of inflation from target Π and of output from yA_t. where y is the steady-state value of normalized output. R marks the steady-state nominal interest rate. The monetary policy shock, ξ_t, follows a $N(0,1)$ process. Regarding the fiscal authority, its budget constraint is given by

$$b_t = b_{t-1}\frac{R_{t-1}}{\Pi_t} + g_t - \left(c_t\tau_{c,t} + w_t l_t \tau_{l,t} + r_{k,t}u_t k_{t-1}\tau_{k,t} - \delta k^b_{t-1}\tau_{k,t} + \Omega_t\right) \tag{2.42}$$

Spending and taxes on consumption and on labor and capital income are set according to fiscal rules described by equations (1) and (2). Lump-sum taxes stabilize the debt-to-output ratio. I impose a passive fiscal/active monetary regime as defined by Leeper (1991):

$$\Omega_t = A_t\left[\Omega + \phi_{\Omega,b}\left(\frac{b_{t-1}}{A_{t-1}y} - \frac{b}{y}\right)\right] \tag{2.43}$$

where $\phi_{\Omega,b} > 0$ and large enough to ensure a stationary debt and b is the steady-state real value of the normalized bonds. Though there is no explicit time-varying volatility for lump-sum taxes. they inherit an implicit time-varying volatility from the other fiscal instruments through the budget constraint and evolution of debt.

2.2.7 Aggregation

Aggregate demand is given by

$$y_t = c_t + i_t + g_t + \frac{\phi_P}{2}(\Pi_t - \Pi)^2 y_t + \frac{\phi_w}{2}(\frac{w_t}{w_{t-1}} - g_A)^2 y_t + \tilde{A}_t\frac{N_{t-1}+B_t}{P_t}\mu\int_0^{\bar{\omega}_t}\omega \mathrm{d}F(\omega) \tag{2.44}$$

Relying on the observation that the capital-labor ratio is the same for all firms and that the capital markets must clear, the aggregate supply is

$$y_t = (u_t k_{t-1})^\alpha (A_t l_t)^{1-\alpha} \tag{2.45}$$

Market clearing requires that

$$y_t = c_t+i_t+g_t+\frac{\phi_p}{2}(\Pi_t-\Pi)^2y_t+\frac{\phi_w}{2}(\frac{w_t}{w_{t-1}}-g_A)^2y_t+\tilde{A}_t\frac{N_{t-1}+B_t}{P_t}\mu\int_0^{\bar{\omega}_t}\omega \mathrm{d}F(\omega) = (u_tk_{t-1})^{\alpha}(A_tl_t)^{1-\alpha} \tag{2.46}$$

Aggregate profits of the firms in the economy are given by

$$F_t = y_t - w_tl_t - r_t^ku_tk_{t-1} - \frac{\phi_p}{2}[\Pi_t - \Pi]^2y_t. \tag{2.47}$$

2.3 Quantitative Analysis

2.3.1 Solution and Calibration

The model is solved by a third-order approximation around its balanced growth path. In the case of a nonlinear solution, the moments of ergodic distribution of endogenous variables can be different from those implied by linearization. Hence, using the methods developed in Andreasen, Fernández-Villaverde and Rubio-Ramírez (2017), this chapter uses a pruned state-space represenattion of the model implied by the third order perturbation. Table 2.1 and table 2.2 list the parameter values used in this chapter. Most of the calibration values in 2.1 come from Fernández-Villaverde et al. (2015) with the exception of those for financial institutions' monitoring cost μ, firms' survival rate ζ and standard deviation for log-normal distribution σ_{FI} which come from Bi et al. (2018). All the values in table 2.2 come from Fernández-Villaverde et al. (2015).

2.3.2 Results

I look at how the model responds to postitive two-standard deviation shock to the capital tax rate. As in Fernández-Villaverde et al. (2015), shocks to tax rates on labor, consumption and government spending does not produce strong enough response and I therefore do not report them here. Figure 2.2 plots the unconditional IRFs. After a volatility shock, we can see a moderate but prolonged drop in output consumption, investment, hours and real wages while inflation and nominal rates rise. The effects become pronounced when the model features financial constraints.

The key transmission mechanism consists of a rise in firm's markup. This markup increases more when firms are financially constrained. After a volatility shock, households face a higher uncertainty to which they respond by consuming and investing less. Due to presence of nominal rigidities, prices do not completely accommodate the lower demand and consequently, demand falls and markups go up. Another reason markups rise is that with Rotemberg pricing, the prices firms choose today affect how costly it will be for them to change it tomorrow. Hence firms bias their pricing upwards. All these effects are magnified when firms are experiencing constraints on their ability to raise finance. As a results, their response to volatility shocks is larger than what it would be in its absence.

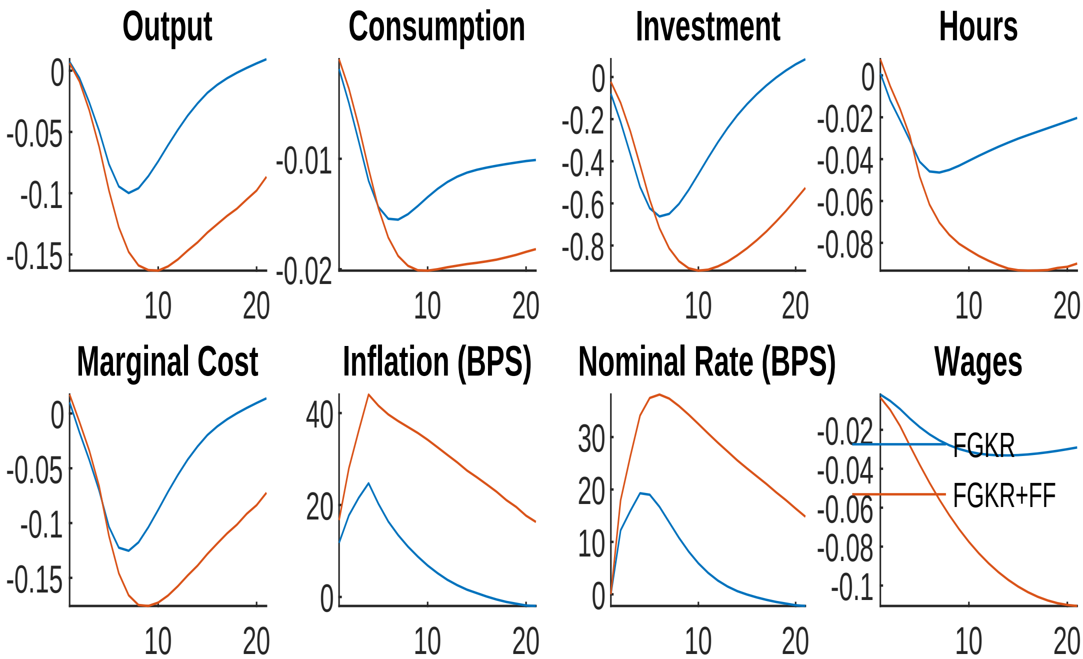

Figure 2.2: Impact of Volatility Shock

2.4 Conclusion

This chapter discusses the amplifying effects of financial frictions when the economy is hit by fiscal volatility shocks. The key finding is that effects of volatility shocks can have more adverse impact depending upon the how financially constrained the borrowers are.

APPENDIX

Assume ω_t is drawn from a log-normal distribution, $\ln(\omega_t) \sim \mathcal{N}(-\frac{1}{2}\sigma_\omega^2, \sigma_\omega^2)$; $\Phi(\cdot)$ and $\phi(\cdot)$ are standard normal cdf and pdf respectively; and $z \equiv (\ln(\bar{\omega}) + 0.5\sigma_\omega^2)/\sigma_\omega$.

$$\begin{aligned}
f(\bar{\omega}_t) &= \int_{\bar{\omega}_t}^{\infty} \omega F(\omega) - (1 - F(\bar{\omega}_t))\bar{\omega}_t \\
&= 1 - \Phi(z_t - \sigma_\omega) - \bar{\omega}[1 - \Phi(z)] && \text{(A.1)} \\
f'(\bar{\omega}_t) &= -\frac{\phi(z_t - \sigma_\omega)}{\sigma_\omega \bar{\omega}_t} - [1 - \Phi(z_t)] + \frac{\phi(z_t)}{\sigma_\omega} && \text{(A.2)} \\
g(\bar{\omega}_t) &= [1 - F(\bar{\omega}_t)]\bar{\omega}_t + (1 - \mu) \int_0^{\bar{\omega}_t} \omega F(\omega) \\
&= [1 - \Phi(z_t)]\bar{\omega}_t + (1 - \mu)\Phi(z_t - \sigma_\omega) && \text{(A.3)} \\
g'(\bar{\omega}_t) &= 1 - \Phi(z_t) - \frac{\phi(z_t)}{\sigma_\omega} + \frac{(1 - \mu)\phi(z_t - \sigma_\omega)}{\sigma_\omega \bar{\omega}_t} && \text{(A.4)} \\
d(\bar{\omega}_t) &= \int_0^{\bar{\omega}_t} \omega F(\omega) = \Phi(z_t - \sigma_\omega) && \text{(A.5)}
\end{aligned}$$

Computation of Impulse Response Functions

A higher order approximation makes the simulated paths of of states and controls in the model away from steady state (see Fernández-Villaverde et al. 2011 and Fernández-Villaverde et al. 2015). In a first order approximation of the model, the expected value of any variable coincides with its value in non-stochastic steady state (thanks to certainty equivalence). In a second order approximation, the expected value of any variable differs from its deterministic steady state value by a constant. It's only in the the third order approximation of the model that higher order terms enter independently and variance of the shocks hitting the economy affects the expected value of the variables. This is why it is more informative to compute impulse response functions as percentage deviations from the mean, rather than steady state values of the variables.

A problem with higher order perturbations is that simulated data series from approximated decision rules often exhibit explosive behavior. This issue can be handled by applying a pruning algorithm such as the one developed in Andreasen, Fernández-Villaverde and Rubio-Ramírez (2017).

Table 2.1: Calibrated values

	A. Households	
β	Subjective discount factor	1.0045
ϑ	Inverse Frisch elasticity of labor supply	2
φ	Risk aversion parameter	1
ψ	Disutility of labor	31.79
b_h	Habit formation	0.75
	B. Retailers	
ϕ_w	Wage adjustment cost	2,513
ϵ_w	Elasticity of substitution among labor types	21
ϕ_p	Price adjustment cost parameter	237.48
ϵ	Elasticity of demand	21
	Financial intermediaries and intermediate goods firms	
μ	FI monitoring cost	0.12
ζ	Firms survival rate	0.93
σ_{FI}	Standard deviation for log-normal distribution	0.7
	C. Policy	
Π	Steady-state inflation	1.0045
ϕ_R	Smoothing coefficient	0.7
γ_Π	Steady-state response to inflation	1.35
γ_y	Steady-state response to output	0.25
Ω	Steady-state level of lump sum taxes	$-5.2e-2$
$\phi_{\Omega,b}$	Response of lump-sum taxes to debt	0.0005
b	Government bonds	2.72
	D. Technology	
α	Capital income share	0.36
δ	Rate of depreciation of capital	0.010
ϕ_1	First derivative for capacity cost utilization	0.0155
ϕ_2	Second derivative for capacity cost utilization	0.01
κ	Coefficient on cost of capacity utilization	0.75
	E. Shocks	
g_A	Steady-state TFP growth rate	1.005
σ_A	Volatility of TFP shock	0.001
ρ_d	Persistence of intertemporal shock	0.18
σ_d	Volatility of intertemporal shock	0.08
σ_m	Steady-state volatility of monetary shock	0.0041

Table 2.2: Calibrated values for fiscal processes

	A. Fiscal Processes - Government spending process	
ρ_g	Autocorrelation	0.99
$\phi_{g,y}$	Response to output	-0.004
$\phi_{g,b}$	Response to debt	-0.008
σ_g	Steady-state volatility	-6.20
ρ_{σ_g}	Persistence of volatility shock	0.92
η_g	Standard deviation of innovation to volatility	0.18
	B. Fiscal Processes - Capital taxes	
ρ_{τ_k}	Autocorrelation	0.98
$\phi_{\tau_k,y}$	Response to output	0.040
$\phi_{\tau_k,b}$	Response to debt	0.003
σ_{τ_k}	Steady-state volatility	-4.90
$\rho_{\sigma_{\tau_k}}$	Persistence of volatility shock	0.65
η_{τ_k}	Standard deviation of innovation to volatility	0.40
	C. Fiscal Processes - Consumption taxes	
ρ_{τ_c}	Autocorrelation	0.99
$\phi_{\tau_c,y}$	Response to output	0.001
$\phi_{\tau_c,b}$	Response to debt	$1e-4$
σ_{τ_c}	Steady-state volatility	-7.12
$\rho_{\sigma_{\tau_c}}$	Persistence of volatility shock	0.73
η_{τ_c}	Standard deviation of innovation to volatility	0.45
	D. Fiscal Processes - Labor taxes	
ρ_{τ_l}	Autocorrelation	0.001
$\phi_{\tau_l,y}$	Response to output	0.18
$\phi_{\tau_l,b}$	Response to debt	0.08
σ_{τ_l}	Steady-state volatility	0.0041
$\rho_{\sigma_{\tau_l}}$	Persistence of volatility shock	0.08
η_{τ_l}	Standard deviation of innovation to volatility	0.0041

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