Targeting Long-Term Rates in a Model with Financial Frictions and Regime Switching*

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Abstract

Decreases (increases) in long-term interest rates caused by compressions (dilations) of term premiums could be financially expansive (contractive) and might require monetary policy restraints (stimulus). This paper uses measures of the term premium calculated by Adrian et al. (2013) to perform Bayesian estimations of a Markov-switching Vector Autoregression (MS-VAR) model as Hubrich and Tetlow (2015), finding evidence of the importance of allowing for switching parameters (non-linearities) and switching variance (non-Gaussian) when analyzing macro-financial linkages in the US. Using the specification with the best fit to the data of 2 Markov states for parameters and 3 Markov states for variances, we estimate a Markov-switching Dynamic Stochastic General Equilibrium (MS-DSGE) macroeconomic model with financial frictions in long-term debt instruments developed by Carlstrom et al. (2017) to provide evidence on how financial conditions have evolved in the U.S. since 1962 and how the Federal Reserve Bank has responded to the evolution of term premiums. Using the estimated model we perform counterfactual analysis of the potential evolution of macroeconomic and financial variables under alternative financial conditions and monetary policy responses. We analyze six episodes with presence of high financial frictions and/or medium and high shocks volatility. In three of them there was a high monetary policy response to financial factors: 1978q4 - 1983q4 which helped to mitigate inflation at the cost of economic activity, and the 1990q2 - 1993q4 and 2010q1 - 2011q4 episodes in which the high response served to mitigate economic contractions. Meanwhile, in the three episodes where low response to financial factors is observed, if the monetary authority had responded more aggressively, from 1971q1 - 1978q3 it could have attained lower inflation at the cost of lower GDP, from 2000q4 - 2004q4 it could have delayed the GDP contraction to 2002q3, but this would have been deeper and inflation larger, and in 2006q1 -2009q4 it might had precipitated the GDP contraction. The presence of high financial frictions and high shock volatility makes recessions deeper and recoveries more sluggish showing the importance of the financial-macroeconomic nexus.

JEL Classification: E12, E43, E44, E52, E58, C11

Keywords: Monetary policy, Term-structure, Financial frictions, Markov-Switching VAR, Markov-Switching DSGE, Bayesian Maximum Likelihood methods.

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"To the extent that the decline in forward rates can be traced to a decline in the term premium, . . . , the effect is financially stimulative and argues for greater monetary policy restraint, all else being equal. Specifically, if spending depends on long-term interest rates, special factors that lower the spread between short-term and long-term rates will stimulate aggregate demand. Thus, when the term premium declines, a higher short-term rate is required to obtain the long-term rate and the overall mix of financial conditions consistent with maximum sustainable employment and stable prices."

- FRB Chairman Ben S. Bernanke, March 20, 2006, "Reflections on the Yield Curve and Monetary Policy."

1 Introduction

The above quote states that yields on long-term debt and specially the term premium, which is the extra compensation required by investors for bearing interest rate risk associated with short-term yields not evolving as expected, are an important determinant of aggregate demand[1]. It also underlies that the monetary authority should respond to term premium movements to stabilize the effects that the financial sector could have in the macroeconomy. However, this task is complicated by the fact that the term premium is not observed and because the mechanisms through which developments in long-term debt instruments affect the macroeconomy are not completely understood.

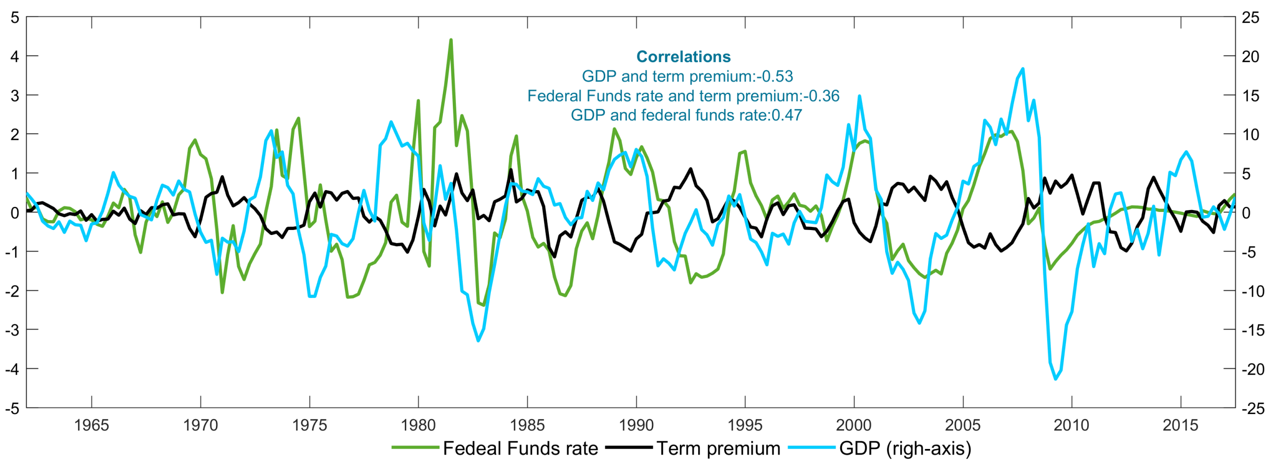

Figure 1: Cyclical movements GDP, Federal Funds Rate and Term premium: 1961q1 - 2017q4. This figure shows the deviation of each original series from its HP filter. GDP is the real gross domestic product (GDPC1 in Fred Economic Data from the Federal Reserve Bank of St. Louis), federal funds rate is the effective federal funds rate (FEDFUNDS also in Fred Economic Data), and term premium is the 10-year Treasury term premium computed following the methodology of Adrian et al. (2013) and reported by the Federal Reserve Bank of New York (ACM10TP).

The Federal Reserve Bank of New York reports a measure of the term-premium calculated by Adrian et al. (2013) which we will use in this study. Before discussing some of the potential mechanisms linking developments in long-term debt markets and the macroeconomy, it is useful to look at the cyclical movements between gross domestic product (GDP), the federal funds rate,

[1] Rudebusch et al. (2006) show that a decline in the term premium has typically been associated with higher future GDP growth.

and the term premium[2]. Figure 1 shows the difference between the observed series and the ones produced by applying a Hodrick Prescott filter. There is a strong negative correlation of -0.53 between the cyclical components of GDP and the term premium. Meanwhile the correlation among the cyclical components of the federal funds rate and the term premium is -0.36 and the correlation among the cyclical components of GDP and the federal funds rate is 0.47.

To further investigate the relationship between long-term debt markets and the macroeconomy, we estimate a Markov-switching Vector Autoregressive model (MS-VAR) following Hubrich and Tetlow (2015), where we replace the post-December 1988 Federal Reserve Board staff's Financial Conditions Index (FCI) with the post-January 1962 term premium, to identify "stress events". First, we analyze if the data favors a Markov-switching specification where coefficients and/or variances are allowed to switch relative to a time-invariant Gaussian VAR model. Our results show that the best fit is attained when we allow for 2 independent Markov states governing the coefficient switching and 3 independent Markov states governing the variance switching in all equations, providing evidence of non-linear and non-Gaussian phenomena. Second, using that preferred specification, we identify the probability of being in a specific coefficient and a specific variance state. Third, the impulse response functions show big differences in the transmission of shocks across different coefficients and variances regimes.

Guided by the 2 coefficient switching and 3 variance switching specification of our MS-VAR, we modify the macroeconomic model with financial frictions in long-term debt instruments developed in Carlstrom et al. (2017) to a Markov-switching Dynamic Stochastic General Equilibrium (MS-DSGE) version. This model helps us to: (i) study how financial conditions, as measure by the degree financial frictions and volatilities of credit market shocks, have evolved in the U.S. since 1962, (ii) measure how the Federal Reserve Bank has responded to the evolution of term premiums, and (iii) to perform counterfactual analysis of the potential evolution of macroeconomic and financial variables under alternative financial conditions, monetary policy responses and credit shock volatilities.

The counterfactual exercises allow to separately analyze the effects of financial frictions, monetary policy responses and the volatility of credit market shocks in the evolution of macroeconomic and financial variables. We analyze six episodes when the estimation assigns a high probability[3] to high financial frictions and/or medium or high shock volatilities. In three of them, 1978q4 - 1983q4, 1990q2 - 1993q4 and 2010q1 - 2011q4, the estimation suggests that monetary policy was responsive to financial conditions with short-term interest rates having a high elasticity to the term premium of -1.16. In the other three episodes, despite the presence of worsening financial conditions, in 1971q1 - 1978q3, 2000q4 - 2004q4, and 2006q1 - 2009q4, the estimation suggests that there was a low response to financial factors with an elasticity of -0.24. The high monetary response allowed the authority to mitigate inflation at the cost of economic activity in the 1978q4 - 1983q4 episode and to mitigate economic contractions in the 1990q2 - 1993q4 and 2010q1 - 2011q4 episodes. If the monetary

[2]We thank Robert E. Lucas for his suggestion of having the high-frequency movements removed using a statistical filter to show if there is a long-run relationship between these three series in a similar way he did to analyze inflation and money growth at https://files.stlouisfed.org/files/htdocs/publications/review/2014/q3/lucas.pdf.

[3]We refer to "large" probability if the probability of a given Markov-state is larger or equal than 50%.

authority had responded more aggressively, when it decided not to, it would have attained lower inflation at the cost of lower GDP in the 1971q1 - 1978q3 episode, would have delayed the GDP contraction to 2002q3, but it would have been deeper and inflation larger in 2000q4 - 2004q4, and it might had precipitated the GDP contraction in 2006q1 -2009q4. The presence of high financial frictions and high shock volatility makes recessions deeper and recoveries more sluggish.

The rest of the paper is organized as follows. Section 2 presents the MS-VAR model including its specification and results. Section 3 presents a MS-DSGE version of a model of segmented financial markets where financial institutions net worth limits the degree of arbitrage across the term structure (a financial friction), a "loan-in-advance" constraint that increases the private cost of purchasing investment goods (creating real effects of the financial frictions), and an augmented monetary policy with response to the term premium. Section 4 discusses the solution and estimation techniques of the MS-DSGE model. Section 5 presents the results showing first the parameter estimates; then the impulse response functions for the different regimes associated to financial frictions, monetary policy and credit shock volatilities; after this we present the regimes probabilities; and finally counterfactual exercises to analyze the role of financial frictions, monetary policy and credit shock volatilities in the evolution of financial and macroeconomic variables in the 1962 – 2017 period. Section 6 presents our conclusions.

2 MS-VAR

In this section we present the MS-VAR model specification and the estimation results which (i) provide evidence on the benefit of allowing for Markov switching in coefficients and variances, while identifying the model with the best goodness-of-fit to the data, (ii) give the coefficient and variances regime probabilities for the model with the largest posterior mode, and (iii) report the impulse response functions comparing the behavior for each coefficient-variance pair.

2.1 Model specification

We introduce a MS-VAR to explore if macroeconomic and financial data provide evidence of switching parameters and switching variance, and to identify periods of high financial stress in the studied sample for the US economy, and hence highlight the importance of introducing these features in a structural modelling framework. We follow the approach presented by Hubrich and Tetlow (2015), which estimates a MS-VAR using the Financial Stress Index (FSI) to measure financial stress, but instead, we propose to use the term premium calculated by Adrian et al. (2013), that we will also use in our structural MS-DSGE, to measure "*financial frictions*".

This specification adopts the spirit of smoothly time-varying parameters in VAR models presented by Primiceri (2005), Cogley and Sargent (2005), and Bianchi and Melosi (2017). Following the notation of Hubrich and Tetlow (2015), the nonlinear system can be written as follows:

$$y_t^{'}A_0\left(s_t^c\right)=\sum_{l=1}^{p}y_{t-l}^{'}A_l\left(s_t^c\right)+z_t^{'}B\left(s_t^c\right)+\varepsilon_t^{'}\Xi^{-1}\left(s_t^v\right) \tag{2.1}$$

where y_t is an $n \times 1$ vector of endogenous variables and A_0 and A_l are $n \times n$ matrices that contains the parameters of the contemporaneous and lagged endogenous variables, respectively; z_t is a $n \times 1$ matrix of endogenous variables and B is a $n \times n$ matrix that include parameters of the exogenous variables. The unobserved states variables s_t^c and s_t^v control the operating regimes for the coefficients and covariance matrix, respectively. These latent variables evolve according to a first-order Markov processes[4] with transition probabilities H^c and H^v, respectively.

We use quarterly data-series for a sample from 1962q1 to 2017q3. In the estimation we use five variables: the log differences of monthly personal consumption expenditures, C_t, log differences of CPI excluding food and energy prices, P_t, nominal interest rate, R_t, growth in the nominal M2 monetary aggregate, M_t, and the term premium, TP_t; which corresponds to the data vector: $y_t = \begin{bmatrix} C_t & P_t & R_t & M_t & TP_t \end{bmatrix}^{'}$. We use the Treasury term premium estimated by Adrian et al. (2013), available at the Federal Reserve Bank of New York website. All the other data are taken from Federal Reserve Bank of St. Louis. Following Sims et al. (2008), standard Minnesota priors are introduced to perform the Bayesian estimation.

2.2 Estimation results

2.2.1 Is there Markov-switching in coefficients and/or variances?

To determine if the data favors a Markov-switching specification where coefficients and/or variances are allowed to switch relative to a time-invariant Gaussian VAR model, we compare the goodness-of-fit of alternative models. Specifically, use $\#c$ to designate the possible states of the Markov chains that govern the slope and intercepts of the coefficients, and $\#v$ to indicate the possible states of the Markov chain governing the switching variance of the system, where $\# = 1, 2,$ and 3. In addition, we could restrict shifts in structural parameters to be constrained to a particular equation(s), indicating by post-fixing the letter(s) of the variable(s), $l = \{\}, C, P, R, M, TP$, where $\{\}$ represents a null entry where parameters are allowed to change in all equations. Then, a model labeled as $1c1v$ corresponds to the time-invariant Gaussian VAR model, while $2c1v$ has 2 regimes for the coefficients with variations in all the equations and 1 regime for the variances, and $2cTPR3v$ has 2 regimes for the coefficients restricted to the term premium and interest rate equations and 3 regimes for the variances.

Table 1 displays the posterior mode for each specification of the model. The models are ordered according to the goodness-of-fit criteria at the mode. Two results are worth noting: First, all the specifications allowing for regime switch are preferred to the constant model version, $1c1v$; second, the model with the best performance is $2c3v$, which allows for two-states in the Markov chain that controls the parameters in coefficients and intercepts simultaneously in all the equations of the

[4] $Pr\left(s_t^y = j \mid s_{t-1}^y = k\right) = p_{jk}^y$, $i, k = 1, 2, \ldots, h^y$, for $y = \{c, v\}$.

Model specification	Posterior density
$2c3v$	-1961.13*
$2cRM3v$	-1986.39
$2cTPRM3v$	-1996.48
$2cRMC3v$	-2008.31
$1c3v$	-2014.16
$2cTP3v$	-2039.96
$3c3v$	-2052.12
$2cTPCP3v$	-2066.24
$2cTPC3v$	-2071.41
$2cTPR3v$	-2074.19
$2c2v$	-2087.19
$1c2v$	-2091.26
$2c1v$	-2116.98
$1c1v$	-2134.26

Table 1: MS-VAR estimation results. Posterior modes are in logarithms for the estimated models..

system and three-states in the Markov chains that control variances; this result is similar to the selected specification in the estimation reported by Hubrich and Tetlow (2015) using the financial stress index for monthly data running from 1988:12 to 2011:12.

2.2.2 Probabilities of switching coefficients and variance states

Figure 2 displays the smoothed probabilities at the posterior mode for the high stress coefficient and the high and medium stress variance for the $2c3v$ MS-VAR model, which is the one with the best fit to the data.

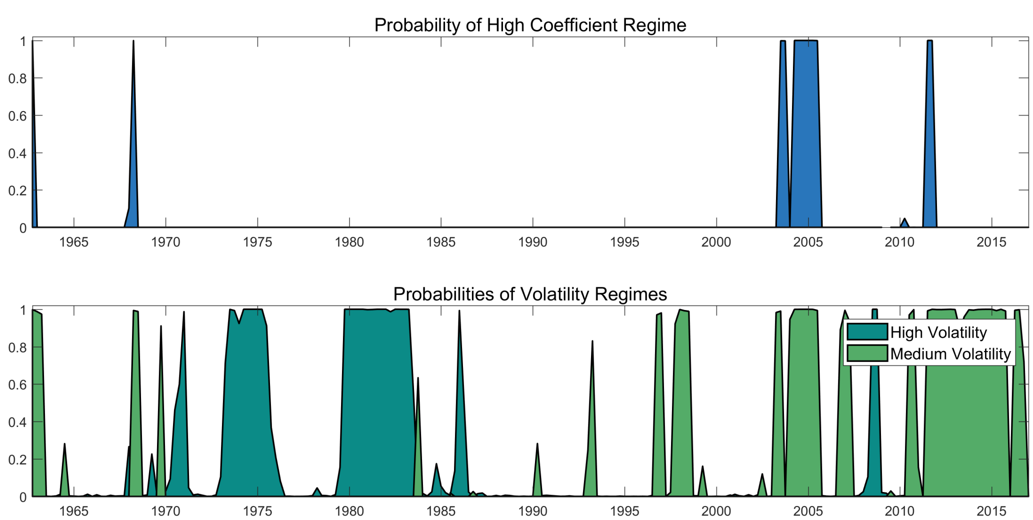

Figure 2: Smoothed probabilities of MS-VAR coefficients and variances regimes. The top panel reports the probability of a High-stress coefficient regime. The second panel reposts the probabilities for the Medium- and High-stress regimes.

The MS-VAR estimation identifies 12 quarters (5.5% of the MS-VAR sample that runs from 1962q4 to 2017q1) with large probability of being in a high-stress coefficient state and the remaining 206 quarters (94.5%) of a low-stress coefficient state[5]. Meanwhile, regarding variance switching the estimation identifies 32 quarters (14.7%) of high probability of being in a high-stress variance state, 49 quarters (22.5%) of medium-stress variance state and 137 quarters (62.8%) of low-stress variance state. We reserve the historical narrative of the regime switching in coefficients and variances to subsection 5.4 when we analyze the regime switches of the DSGE models.

2.2.3 MS-VAR impulse response functions

Figure 3 displays the impulse response functions for the $2c3v$ MS-VAR model, which is the one with the best fit to the data. There we see that the varying coefficients and the varying volatilities generate different responses for any given variable. The important differences in magnitude and persistence for the high (reds) versus low (blues) coefficient regimes, which yields a distorting scale in some responses, are notable. Also, there are significant differences in the responses when comparing the high, medium and low variance regimes (darker color). For example, for a term premium shock, a high coefficient regime has a transitory effect on term premiums, a sharp drop in consumption growth and raising interest rates, which contrast with the low coefficient regime where the effect on term premium lasts longer and there is no contraction in consumption growth, neither changes in interest rates. Other example is the behavior of the variables to an interest rate shock, where under the high coefficient regime, the term premium raises sharply and consumption growth declines, with the exception when the high coefficient regime intersects with the low variance regime (which only occurred in 2003q4) where some of the dynamics are closer to the low coefficient regime.

Our estimations are consistent with empirical econometric approaches that model the role of financial frictions as a source of shock amplification allowing for Markov-switching dynamics using VAR models for the US economy (see. Davig and Hakkio (2010) and Hubrich and Tetlow (2015)). Guided by the evidence in this MS-VAR of varying coefficients and variances, we now move to a MS-DSGE model with macro-financial linkages to analyze potential mechanisms.

3 MS-DSGE model

Although the less restrictive MS-VAR econometric approach allows us to identify regime switches, it does not allow us to give an economic interpretation to the changes in parameters and variances. We will explore the possibility that the observed regime changes are related to shifts in financial

[5] The results for the 2c3v model do not show many switches in the probabilities of the coefficients. However, if we restrict the model to other specifications in the interest rate, money supply and term premium equations, such as 2cRM3v, 2cTPR3v and 2cTPRM3v the smoothed probabilities for the coefficients have more fluctuation. These models report frictions for the coefficient in the following percentages of the sample: 18%, 32%, and 32%, respectively. As we show in section in section 5.3, these results are more consistent with the MS-DSGE specification results, where high financial frictions are present in 26.5% of the sample, while high monetary policy response is present in 19.3%.

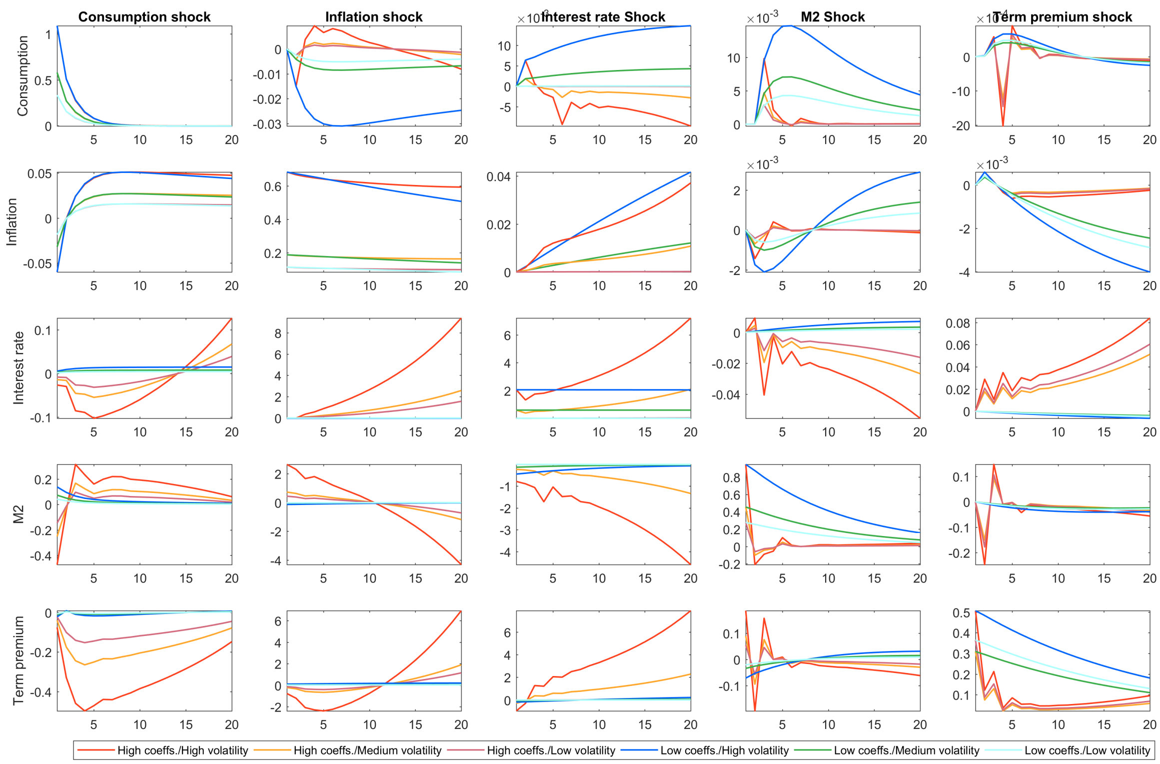

Figure 3: Impulse response functions for the 5 equations of the $2c3v$ MS-VAR. High corfficient regimes are presented in reds/yellows, while low coefficient regimes are shown in blues/greens colors. The darker the color of the line, the greater the variance volatility regime.

conditions through changes in financial frictions and the volatility of credit market shocks. To do so, we use the model proposed by Carlstrom et al. (2017), and allow for two coefficient regimes associated to financial frictions and three variance regimes ordered by the volatility of credit market shocks. In addition, to analyze if monetary policy responded to those financial conditions, we allow for two independent regime shifts of a term premium-augmented monetary policy interest rate reaction functioni. Using the model we will identify how financial frictions, credit market shock volatilities and monetary policy have evolved in the US since 1962. The estimated model will provide us with a consistent framework to perform counterfactual analysis of what could have happened under alternative financial conditions, credit shock variances and monetary policy responses.

3.1 Model

This section presents the key elements of the DSGE model in Carlstrom et al. (2017) with our Markov-switching modification in the parameters that capture financial frictions, monetary policy responses and stochastic volatility of all the shocks in the model. Potential regime changes in financial frictions are captured by changes in the parameter associated to FIs' portfolio adjustment costs, ψ_n which is also related to the FIs holdup problem. We use a state variable ξ_t^{ff}, to distinguish the level of financial friction regime at time t. Meanwhile regime changes in the monetary policy's response to the term premium, where we use a state variable ξ_t^{mp}, to differentiate among elasticities of short-term interest rates to the term premium τ_{tp} regime at time t. Concurrently, to allow for regime changes in the stochastic volatilities we model a third independent Markov-switching process and use a state variable ξ_t^{vol} to distinguish the volatility regime at time t.

To make the paper self-contained, Appendix A presents the whole model following exactly the description in Carlstrom et al. (2017), but we strongly suggest the reader to read their paper for further analysis. The economy consists of households, financial intermediaries (FIs) firms and gov't agencies. Many of the ingredients are standard with the chief novelty coming from their assumptions on household-FI interactions. Specifically, households do not have access to long-term debt markets, while FI intermediaries do, creating a credit market segmentation. Households face a loan-in-advance constraint to finance investment which gives market segmentation a relevant role for real allocations. FIs have a hold-up problem as they can default on depositors which could only recover a fraction $(1-\Psi_t)$ of the FI's assets, where Ψ_t is a decreasing function of FI's net worth, creating a financial-accelerator type of mechanism. FIs face portfolio adjustment costs which limits its ability to respond to changes in the governments relative supply of long-term debt having effects on lending and investment, as net worth and deposits cannot quickly sterilize central bank long-term debt purchases. Finally, the central bank interest rate reaction function is augmented with a potential response to the term-premium. These are the key elements of the macro-financial-monetary policy nexus of the model highlighted here.

We leave for Appendix A the description of households supply of monopolistically specialized labor as in Erceg et al. (2000) which serves to introduce wage rigidities and wage markup shocks. Also, the perfectly competitive final good producer problem which yields the aggregation of a continuum of intermediate goods for aggregate supply. The monopolistic competitive intermediate goods producers problem is introduced as in Yun (1996). This firms are also used to introduce neutral technology shocks and price rigidities and price markup shocks. The new capital producers problem which transforms investment goods into new capital goods through an investment adjustment costs and introduces an investment-specific technology shock.

Households

Each household chooses consumption, C_t, labor supply, H_t, short-term deposits in the FI, D_t, investment bonds, F_t, investment, I_t, and next-period physical capital K_{t+1} to maximize the optimization problem given by:

$$\max_{C_t,H_t,D_t,F_t,I_t,K_{t+1}} E_0 \sum_{s=0}^{\infty} \beta^s e^{rn_{t+s}} \left\{ ln(C_{t+s} - hC_{t+s-1}) - L\frac{H_{t+s}^{1+\eta}}{1+\eta} \right\} \tag{3.1}$$

subject to:

$$C_t + \frac{D_t}{P_t} + P_t^k I_t + \frac{F_{t-1}}{P_t} \leq W_t H_t + R_t^k K_t - T_t + \frac{D_{t-1}}{P_t} R_{t-1} + \frac{Q_t(F_t - \kappa F_{t-1})}{P_t} + div_t \tag{3.2}$$

$$K_{t+1} \leq (1-\delta)K_t + I_t \tag{3.3}$$

$$P_t^k I_t \leq \frac{Q_t(F_t - \kappa F_{t-1})}{P_t} = \frac{Q_t CI_t}{P_t} \tag{3.4}$$

Before defining the variables and parameters, it is important to highlight that households do not have access to long-term bonds, while FIs do, creating a market segmentation. Also, very important for the macro-financial nexus, equation (3.4) is a loan-in-advance constraint through which all investment purchases must be financed by issuing "investment bonds, F_t, that are purchased by the FI. The endogenous behavior of the distortion related to Lagrange multiplier of the loan-in-advance constraint is fundamental for the real effects arising from market segmentation.

In this optimization, $h \in (0,1)$ is the degree of habit formation, $\beta^t \in (0,1)$ is the discount factor which has intertemporal preferences shocks, e^{rn}, which follows the stochastic process $rn_t = \rho_{rn} rn_{t-1} + \sigma_{rn,\xi_t^{vol}} \varepsilon_{rn,t}$, where $\sigma_{rn,\xi_t^{vol}}$ is the standard deviation of the stochastic volatility of the intertemporal preferences $\varepsilon_{rn,t}$ ~ i.i.d. N(0, σ^2_{rn}), whose ξ_t^{vol} subscript denotes that it is allowed to change across regimes at time-t. We follow the same convention in the notation for each shock. Aside from this switching volatility, the household problem does not have switching coefficients.

Equation (3.2) tells us that households sources of income are: labor supply with real wage W_t; capital rents at a real rate R_t^k; previous period deposit holdings with gross nominal interest rate R_{t-1}; new issues of perpetuities of investment bonds $CI_t = F_t - \kappa F_{t-1}$ with price Q_t; and dividend flow from the FIs div_t.[6] Households uses their resources to: pay lump-sum taxes T_t; consumption, deposit at FIs, buy investment goods with real price of capital P_t^k and pay for outstanding investment bonds. P_t is the price level. Meanwhile, equation (3.3) is the standard capital accumulation equation with depreciation rate δ and, as already mentioned, equation (3.4) is the loan-in-advance constraint for investment purchases.

Financial Intermediaries

FIs choose net worth, N_t, and dividends to maximize its value function, V_t, to solve the optimization problem given by:

$$V_t \equiv \max_{N_t, div_t} E_t \sum_{j=0}^{\infty} (\beta\zeta)^j \Lambda_{t+j} div_{t+j} \tag{3.5}$$

subject to the resource constraint :

$$div_t + N_t \left[1 + f(N_t)\right] \leq \frac{P_{t-1}}{P_t} \left[(R_t^L - R_{t-1}^d) L_{t-1} + R_{t-1}^d\right] N_{t-1} \tag{3.6}$$

and the incentive compatibility constraint that ensures that the FI repays deposits, given that depositors can seize at most a fraction $(1 - \Psi_t)$ of the FI's assets:

$$E_t V_{t+1} \geq \Psi_t E_t R_{t+1}^L \left(\frac{D_t}{P_t} + N_t\right) \tag{3.7}$$

[6] The household also receives a profit flow from the intermediate goods producers and the new capital producers, but to simplify notation, this part is omitted.

where $\zeta \in (0,1)$ is an additional impatience to prevent that the short-term and long-term market segmentation vanishes through "excessive" accumulation of net worth, Λ_t is the household's marginal utility of consumption.

Regarding the resource constraint, FIs uses accumulated net worth, N_t, and short-term liabilities, D_t, to finance investment bonds, F_t, and the long-term bonds B_t. The FI's balance sheet is thus given by $\frac{B_t}{P_t}Q_t + \frac{F_t}{P_t}Q_t = \frac{D_t}{P_t} + N_t = L_t N_t$ where Q_t is the price of a new- debt issue at time-t and $L_t = \frac{\frac{D_t}{P_t}+N_t}{N_t}$, denotes leverage. Profits are given by $prof_t \equiv \frac{P_{t-1}}{P_t}\left[\left(R_t^L - R_{t-1}^d\right)L_{t-1} + R_{t-1}^d\right]N_{t-1}$, where $R_t^L \equiv \left(\frac{1+\kappa Q_t}{Q_{t-1}}\right)$ is the return on lending, R_t^d is the the interest rate on deposits. On the left hand side of equation (3.6), those profits are used to distribute dividends and accumulate net worth which has an adjustment cost function $f(N_t) \equiv \frac{\psi_{n,\xi_t^{ff}}}{2}(\frac{N_t - N_{ss}}{N_{ss}})^2$ that dampens the ability of the FI to adjust the size of its portfolio in response to shocks. The ξ_t^{ff} subscript indicates that this financial market segmentation parameter, which is related to financial frictions, is allowed to change across regimes at time t.

Assuming that $\Psi_t \equiv \Phi_t\Big[1 + \frac{1}{N_t}\left(\frac{E_t g_{t+1}}{E_t X_{t+1}}\right)\Big]$, is a function of net worth in a symmetric manner with $f(N_t)$, the binding incentive constraint (3.7), which yields leverage as a function of aggregate variables but independent of each FI's net worth, is given by:

$$E_t\frac{P_t}{P_{t+1}}\Lambda_{t+1}\left[\left(\frac{R_{t+1}^L}{R_t^d}-1\right)L_t+1\right] = \Phi_t L_t E_t \Lambda_{t+1}\frac{P_t}{P_{t+1}}\frac{R_{t+1}^L}{R_t^d} \tag{3.8}$$

Then, the FI's optimal accumulation decision is given by:

$$\Lambda_t\left[1 + N_t f'(N_t) + f(N_t)\right] = E_t\beta\zeta\Lambda_{t+1}\frac{P_t}{P_{t+1}}\left[\left(R_{t+1}^L - R_t^d\right)L_t + R_t^d\right] \tag{3.9}$$

where $\Phi_t \equiv e^{\phi_t}$ is a credit shock that in logarithms follows an AR(1) process:

$$\phi_t = (1-\rho_\phi)\phi_{ss} + \rho_\phi\phi_{t-1} + \sigma_{\phi,\xi_t^{vol}}\varepsilon_{\phi,t} \tag{3.10}$$

where $\sigma_{\phi,\xi_t^{vol}}$ is the standard deviation of the stochastic volatility of the credit shock, $\varepsilon_{\phi,t}$ ~ i.i.d. N(0, σ_ϕ^2), whose ξ_t^{vol} subscript denotes that it is allowed to change across regimes at time t. When we allow for regime switching in volatilities, regimes will be classified by the magnitude of this shock.

Increases in ϕ_t will exacerbate the hold-up problem, and act as "credit shocks", which will increase the spread and lower real activity.

The Effect of Financial Friction

To gain further intuition of the financial frictions, first log-linearize the FI incentive compatibility constraint (3.8) and the FI optimal net worth accumulation decision (3.9) to get:

$$E_t(r_{t+1}^L - r_t) = \upsilon l_t + \left[\frac{1+(s-1)L_{ss}}{L_{ss}-1}\right]\phi_t \tag{3.11}$$

and

$$\psi_{n,\xi_t^{ff}} n_t = \left[\frac{sL_{ss}}{1+L_{ss}(s-1)}\right] E_t(r_{t+1}^L - r_t) + \left[\frac{(s-1)L_{ss}}{1+L_{ss}(s-1)}\right] l_t \tag{3.12}$$

where $\upsilon \equiv (L_{ss}-1)^{-1}$ is the elasticity of the interest rate spread to leverage; s denotes the gross steady-state premium. Equation (3.11) is quantitatively identical to the corresponding relationship in the more complex costly state verification (CSV) environment of Bernanke et al. (1999). Combining (3.11) and (3.12), we get the following expression:

$$E_t(r_{t+1}^L - r_t) = \frac{1}{L_{ss}} \psi_{n,\xi_t^{ff}} n_t + (s-1)\phi_t \tag{3.13}$$

This expression shows the importance of $\psi_{n,\xi_t^{ff}}$ for the supply of credit. If $\psi_{n,\xi_t^{ff}} = 0$, the supply of credit is perfectly elastic, independent of the financial intermediaries net worth. As $\psi_{n,\xi_t^{ff}}$ becomes larger, the financial friction becomes more intense and the supply of credit depends positively on the financial intermediaries net worth.

Fiscal Policy

Fiscal policy is entirely passive. Government expenditures are set to zero. Lump-sum taxes move endogenously to support the interest payments on the short and long-term debt.

Debt Market Policy

We consider a policy regime of exogenous debt. Long-term debt is assume to follow:

$$b_t = \rho_1^b b_{t-1} + \rho_2^b b_{t-2} + \epsilon_{b,t} \tag{3.14}$$

where $b_t \equiv ln\left(\frac{\overline{B}_t}{\overline{B}_{ss}}\right)$ and could fluctuate due to long bond purchases (QE) or changes in the mix of short debt to long debt in its maturity. An AR(2) process to be consistent with the QE policy and denote the persistence of the monetary policy shock.

Central Bank Policy

We assume that the central bank follows a term premium (tp_t) augmented Taylor rule over the short rate (T- bills and deposits):

$$ln(R_t) = \rho_{R,\xi_t^{mp}} ln\left(R_{t-1}\right) + \left(1-\rho_{R,\xi_t^{mp}}\right)\left(\tau_{\pi,\xi_t^{mp}}\pi_t + \tau_{y,\xi_t^{mp}} y_t^{gap} + \tau_{tp,\xi_t^{mp}} tp_t\right) + \sigma_{r,\xi_t^{vol}}\epsilon_{r,t} \tag{3.15}$$

where $y_t^{gap} \equiv (Y_t - Y_t^f)/Y_t^f$ denotes the deviation of output from its flexible price counterpart, π_t is CPI inflation rate, and $\epsilon_{r,t}$ is an exogenous and auto-correlated policy shock with AR(1) coefficient ρ_m. The coefficient $\rho_{R,\xi_t^{mp}}$ captures the degree of persistence of the interest rate, and the parameters $\tau_{\pi,\xi_t^{mp}}$, $\tau_{y,\xi_t^{mp}}$ and $\tau_{tp,\xi_t^{mp}}$, capture the elasticity of the interest rate to inflation, output gap, and term premium, respectively. ξ_t^{mp} indicates that these parameters are allowed to change across regime at time t. We will order regimes according to the relative response to the term premium.

The term premium is defined as the difference between the observed yield on a ten-year bond and the corresponding yield implied by applying the expectation hypothesis (EH) of the term structure to the series of short rates.

4 Solution and Estimation of the MS-DSGE model

4.1 MS-DSGE solution methods

Given that the traditional stability concepts for constant DSGE models does not hold for the Markov-switching case, to solve the linear version of the model we use the solution method proposed by Maih (2015),[7] which uses the minimum state variable (MSV)[8] concept to present the solution of the system in the following form:

$$X_t\left(s_t, s_{t-1}\right) = T\left(\xi_t^{sp}, \theta^{sp}\right) X_{t-1}\left(s_{t-1}, s_{t-2}\right) + R\left(\xi_t^{vo}, \theta^{sp}\right) \varepsilon_t \tag{4.1}$$

where T and R matrices contains the model's parameters. X_t stands for the $(n \times 1)$ vector of endogenous variables, ε_t is the $(k \times 1)$ vector of exogenous processes.

As mentioned in the previous section, we introduce the possibility of regime change for two structural parameters (sp) and to shock volatilities(vo) through three independent Markov chains: ξ_t^{ff}, ξ_t^{mp} and ξ_t^{vol}, respectively. The three chains denote the unobserved regimes associated with the market segmentation, $\psi_{n,\xi_t^{ff}}$, monetary policy response to the term premium, $\tau_{tp,\xi_t^{mp}}$, and volatilities. These processes are subject to regime shifts and takes on discrete values $i \in \{1, 2\}$, where regime 1 implies high absolute values for parameters of market segmentation, monetary policy response to the term premium and volatilities, and the opposite is true for low parameters.[9]

The three Markov chains are assumed to follow a first-order process with the following transition matrices, respectively:

$$H^i = \begin{pmatrix} H_{12} & H_{12} \\ H_{21} & H_{22} \end{pmatrix} \; for\ i = ff,\ mp,\ vol \tag{4.2}$$

where $H_{ij} = p\left(sp_t = j \mid sp_{t-1} = i\right)$, for $i, j = 1, 2$. Then, H_{ij} stands for the probability of being in regime j at t given that one was in regime $t - 1$.

Various authors have focused in the concept of Mean Square Stability solutions (MSS)[10] for (4.1). As is emphasized by Maih (2015) and Foerster (2016), this condition implies finite first and second moments in expectations for the system:

[7] Based in perturbation methods as the approach presented by Barthélemy and Marx (2011) and Foerster et al. (2014).

[8] See McCallum (1983).

[9] The identification for each regime will be described in detail in subsection 4.4.

[10] See Costa et al. (2006); Cho (2014); Foerster et al. (2014); Maih (2015).

$$\lim_{j\to\infty} \mathbb{E}_t\left[X_{t+j}\right] = \bar{x} \tag{4.3}$$

$$\lim_{j\to\infty} \mathbb{E}_t\left[X_{t+j}X'_{t+j}\right] = \sum \tag{4.4}$$

Additionally, as pointed by Costa et al. (2006), and Foerster (2016), the solution of the system (4.1) given that the matrix $T\left(\xi^{sp}, \theta^{sp}, H\right)$ does not satisfy the standard stability condition, a necessary and sufficient condition of MSS stability implies that all the eigenvalues of the matrix Ψ are in the unit circle (Alstadheim et al., 2013):

$$\Psi = \left(\mathbb{H} \otimes I_{n^2}\right) \begin{bmatrix} T_1T_1 & & \\ & \ddots & \\ & & T_hT_h \end{bmatrix} \tag{4.5}$$

Finally, to complete the state form of the model, (4.1) is combined with the measurement equation (4.6):

$$Y_t^{obs} = MX_t \tag{4.6}$$

where Y_t^{obs} are the observables.

4.2 MS-DSGE estimation methods

The standard Kalman filter cannot be used to compute the likelihood, because of the presence of unobserved states of the Markov chains, the filtering inferences have to be conditioned on information of the current and past state of the system, s_t and s_{t-1}, respectively. If the filter takes into account all the possible paths of the system, in each iteration, these will be multiplied by the number of possible regimes, h. In a few number of steps, the number of paths of the systems would increase, making the computation of the problem infeasible Alstadheim et al. (2013). To make treatable this problem, Kim and Nelson (1999) propose an approximation that average across states[11]. Following the approach outlined in Alstadheim et al. (2013) and Bjørnland et al. (2018a), an averaging operation (collapse) is applied during the filtering procedure. This form of computation has computational savings and also similar numeric results to the Kim-Nelson approach (Kim and Nelson, 1999; Bjørnland et al., 2018a).

This paper uses the Bayesian approach to estimate the model with the following procedure:

1. We compute the solution of the system using an algorithm found in Maih (2015), and employing a modified version of the Kim and Nelson (1999) filter to compute the likelihood with the prior distribution of the parameters.

2. Construct the posterior kernel result from stochastic search optimization routines[12].

[11] This algorithm involves running the Kalman-filter for each of the paths and the taking a weighted average using the weights given by the probability assigned to each path from the filter proposed in Hamilton (1989).

[12] Provided in the RISE toolbox

3. We use the mode of the posterior distribution as the initial value for a Metropolis Hasting algorithm[13], with 50,000 iterations, to construct the full posterior distribution.

4. Utilizing mean and variance of the last 40,000 iterations we compute moments.

4.3 Database

We use US data from 1962q1 to 2017q3 for the estimation of the model. The database take the original series reported in Carlstrom et al. (2017) but extend the sample from 2008q4 to 2017q3.

Quarterly series for the annualized growth rates of real GDP, real gross private domestic investment, real wages, inflation rate - PCE index - and real wages[14]. The labor input series was constructed substituting the trend component from the non-farm business sector (hours of all persons) series. The series for the FFR is obtained averaging monthly figures downloaded from the St. Louis Fed web-site. Additionally, for the term premium, we take the Treasury Term Premia series from the New York Fed web-site, estimated by Adrian et al. (2013). All data are demeaned.

4.4 Prior Specification

Following Carlstrom et al. (2017), we calibrate several parameters to match the long-run features of the US data, which are reported in Table 2. Regarding the non-switching block of parameters in the model, following Bjørnland et al. (2018b), rather than setting means and standard deviations for the prior densities, these are set using quantiles of the distributions. Specifically, we use 90% probability intervals of the respective distribution to uncover the underlying hyperparameters, based on the results reported by Carlstrom et al. (2017). The choice of prior distributions for the constant and switching parameters are displayed in the right panel of Tables 3 and 4, respectively.

Table 2: Calibrated parameters

Parameter	value
β	0.99
α	0.33
δ	0.025
$\rho_{r_t^{10}}$	0.85
$\epsilon_p = \epsilon_w$	5
L_{ss}	6
s	0.01
R^L_{ss}	$1/\beta$
$(1-\kappa)^{-1}$	40

For identification purposes, we characterized the high financial market segmentation regime, $\xi_t^{ff} = 1$, to be a regime where credit market present high portfolio adjustment cost (i.e. $\psi_{n,\xi_t^{ff}=1} >$

[13]With an acceptance ratio of $\alpha = 0.28$.
[14]Defined as nominal compensation in the non-farm business sector divided by the consumption deflator.

$\psi_{n,\xi_t^{ff}=2}$). Meanwhile, for regime changes in the monetary policy's response to term premium, we define, $\xi_t^{mp} = 1$, to be the regime where the Central Bank responds strongly to changes in this variable (i.e. $\left|\tau_{tp,\xi_t^{mp}=1}\right| > \left|\tau_{tp,\xi_t^{mp}=2}\right|$). The model also allows for regime switching in all the shocks, thus we let the volatility shocks to follow an independent three-state Markov-process. Then, we indicate the high, medium and low volatility regimes, $\xi_t^{vol} = 1$, $\xi_t^{vol} = 2$ and $\xi_t^{vol} = 3$, respectively, which implies the following non-linear restriction: $\sigma_{\phi,\xi_t^{vol}=1} > \sigma_{\phi,\xi_t^{vol}=2} > \sigma_{\phi,\xi_t^{vol}=3}$.

5 MS-DSGE estimation results

5.1 Parameter estimation

In this section, we report the posterior parameter estimates. The Bayesian estimation uses the posterior mode as initial value. Table 3 reports the estimates of the constant parameters, while table 4 reports the estimates of the switching parameters, shocks standard deviations and elements of the transition matrices. We focus our discussion on the results of the switching elements.

Constant parameters								
Parameter	**Density**	**Posterior**				**Prior**		
		Mean	**Mode**	**10%**	**90%**	**Mode**	**10%**	**90%**
η	*Gamma*	1.4324	1.4633	1.1024	1.7624	2.0259	1.2673	2.7526
h	*Beta*	0.6890	0.7014	0.6367	0.7412	0.6225	0.5760	0.6687
ψ_i	*Gamma*	3.4380	3.2967	2.9914	3.8846	3.2821	2.1857	4.3639
ι_p	*Beta*	0.4118	0.4201	0.2103	0.6133	0.4172	0.2752	0.5610
ι_w	*Beta*	0.5109	0.5157	0.39871	0.6231	0.5110	0.4085	0.6205
κ_{pc}	*Beta*	0.1000	0.0966	0.00135	0.1986	0.0860	0.0104	0.1544
κ_w	*Beta*	0.0057	0.0054	0.00201	0.0093	0.0002	0.0001	0.0004
ρ_a	*Beta*	0.9659	0.9412	0.9421	0.9898	0.9921	0.9841	0.9997
ρ_μ	*Beta*	0.8483	0.8364	0.7853	0.9112	0.8695	0.8281	0.9122
ρ_ϕ	*Beta*	0.9919	0.9871	0.9878	0.9960	0.9821	0.9682	0.9963
ρ_{mk}	*Beta*	0.5312	0.5501	0.4302	0.6322	0.6650	0.4945	0.8405
ρ_w	*Beta*	0.3798	0.3706	0.3556	0.4039	0.2059	0.1036	0.3027
ρ_m	*Beta*	0.2240	0.2503	0.0516	0.3963	0.1564	0.0646	0.2515
ρ_{rn}	*Beta*	0.9126	0.9361	0.93164	0.9936	0.9483	0.9212	0.9751

Table 3: Posterior means, modes, and 90% probability intervals of the constant-block parameters.

The first thing to notice is that there are big differences in the parameter that characterizes the financial frictions related to the financial intermediaries hold-up problem. Remember that if $\psi_n = 0$, the supply of credit is perfectly elastic, independent of the financial intermediaries net worth, while as ψ_n becomes larger, the financial friction becomes more intense and the supply of credit depends positively on the financial intermediaries net worth. As is shown later in figures 4 and 5, the high financial frictions regime, with $\psi_{n,\xi_t^{ff}=1} = 1.98$, gives an important role to financial factors into the macroeconomic determination, while the low financial frictions regime, with $\psi_{n,\xi_t^{ff}=2} = 0.11$, is

Switching parameters, variances and transition matrices							
Parameter	**Density**	**Posterior**				**Prior**	
		Mean	**Mode**	**10%**	**90%**	**Mean**	**Std. dev.**
$\psi_{n,\xi_t^{ff}=1}$	*Uniform*	1.9778	1.9928	1.6412	2.3143	1	0.5
$\psi_{n,\xi_t^{ff}=2}$	*Uniform*	0.1060	0.0870	0.0124	0.1996	1	0.5
$\tau_{tp,\xi_t^{mp}=1}$	*Normal*	-1.1597	-1.2100	-1.2280	-1.0914	-1	0.5
$\tau_{tp,\xi_t^{mp}=2}$	*Normal*	-0.2395	-0.3352	-0.3564	-0.1226	-0.5	0.5
$\rho_{R,\xi_t^{mp}=1}$	*Beta*	0.65065	0.8016	0.5401	0.7612	0.5	0.3
$\rho_{R,\xi_t^{mp}=2}$	*Beta*	0.79565	0.8016	0.7401	0.8512	0.5	0.3
$\tau_{\pi,\xi_t^{mp}=1}$	*Normal*	1.3659	1.2864	1.2813	1.4505	1.5	0.5
$\tau_{\pi,\xi_t^{mp}=2}$	*Normal*	1.7504	1.6697	1.6532	1.8477	1.5	0.5
$\tau_{y,\xi_t^{mp}=1}$	*Normal*	0.1330	0.1276	0.1123	0.1538	0.5	0.3
$\tau_{y,\xi_t^{mp}=2}$	*Normal*	0.0778	0.0771	0.0635	0.0921	0.5	0.3
$\sigma_{\phi,\xi_t^{vol}=1}$	*Inv. Gamma*	7.5666	7.5643	6.1589	8.9712	0.5	1
$\sigma_{\phi,\xi_t^{vol}=2}$	*Inv. Gamma*	4.0118	4.1237	3.1283	4.8953	0.5	1
$\sigma_{\phi,\xi_t^{vol}=3}$	*Inv. Gamma*	3.8361	3.8928	3.0082	4.6640	0.5	1
$\sigma_{a,\xi_t^{vol}=1}$	*Inv. Gamma*	0.78675	0.8025	0.7581	0.8154	0.5	1
$\sigma_{a,\xi_t^{vol}=2}$	*Inv. Gamma*	0.6029	0.6087	0.5664	0.6394	0.5	1
$\sigma_{a,\xi_t^{vol}=3}$	*Inv. Gamma*	0.44625	0.4314	0.3733	0.5192	0.5	1
$\sigma_{\mu,\xi_t^{vol}=1}$	*Inv. Gamma*	7.63225	7.6133	7.6041	7.6604	0.5	1
$\sigma_{\mu,\xi_t^{vol}=2}$	*Inv. Gamma*	4.3343	4.2359	4.0826	4.586	0.5	1
$\sigma_{\mu,\xi_t^{vol}=3}$	*Inv. Gamma*	2.16765	2.1365	2.0281	2.3072	0.5	1
$\sigma_{mp,\xi_t^{vol}=1}$	*Inv. Gamma*	0.46385	0.3254	0.2815	0.6462	0.5	1
$\sigma_{mp,\xi_t^{vol}=2}$	*Inv. Gamma*	0.1371	0.1282	0.0953	0.1789	0.5	1
$\sigma_{mp,\xi_t^{vol}=3}$	*Inv. Gamma*	0.10995	0.1088	0.0944	0.1255	0.5	1
$\sigma_{mk,\xi_t^{vol}=1}$	*Inv. Gamma*	0.41	0.4068	0.3741	0.4459	0.5	1
$\sigma_{mk,\xi_t^{vol}=2}$	*Inv. Gamma*	0.31185	0.3047	0.2826	0.3411	0.5	1
$\sigma_{mk,\xi_t^{vol}=3}$	*Inv. Gamma*	0.2422	0.2389	0.2217	0.2627	0.5	1
$\sigma_{w,\xi_t^{vol}=1}$	*Inv. Gamma*	1.1244	1.09	1.0818	1.167	0.5	1
$\sigma_{w,\xi_t^{vol}=2}$	*Inv. Gamma*	0.50945	0.4953	0.4862	0.5327	0.5	1
$\sigma_{w,\xi_t^{vol}=3}$	*Inv. Gamma*	0.4305	0.4257	0.3989	0.4621	0.5	1
$\sigma_{rn,\xi_t^{vol}=1}$	*Inv. Gamma*	0.2338	0.2223	0.2146	0.253	0.5	1
$\sigma_{rn,\xi_t^{vol}=2}$	*Inv. Gamma*	0.0838	0.0793	0.0723	0.0953	0.5	1
$\sigma_{rn,\xi_t^{vol}=3}$	*Inv. Gamma*	0.0677	0.0635	0.0559	0.0795	0.5	1
$H_{1,2}^{ff}$	*Dirichlet*	0.2072	0.2126	0.1803	0.2341	0.05	0.03
$H_{2,1}^{ff}$	*Dirichlet*	0.2003	0.1974	0.1696	0.2310	0.05	0.03
$H_{1,2}^{mp}$	*Dirichlet*	0.0850	0.0845	0.0719	0.0981	0.05	0.03
$H_{2,1}^{mp}$	*Dirichlet*	0.0374	0.0443	0.0216	0.0532	0.05	0.03
$H_{1,2}^{vol}$	*Dirichlet*	0.0144	0.0100	0.0053	0.0235	0.05	0.03
$H_{1,3}^{vol}$	*Dirichlet*	0.0697	0.0660	0.0560	0.0833	0.05	0.03
$H_{2,1}^{vol}$	*Dirichlet*	0.1719	0.1801	0.1528	0.1910	0.05	0.03
$H_{2,3}^{vol}$	*Dirichlet*	0.1907	0.1803	0.1697	0.2117	0.05	0.03
$H_{3,1}^{vol}$	*Dirichlet*	0.1728	0.1811	0.1459	0.1996	0.05	0.03
$H_{3,2}^{vol}$	*Dirichlet*	0.1776	0.1816	0.1569	0.1982	0.05	0.03

Table 4: Posterior means, modes, and 90% probability intervals of the switching-block parameters, shocks standard deviations and transition matrices. The reported priors for Dirichlet distributions correspond to the resultant transition probabilities of the respective hyperparameters combination.

close to a frictionless case, where financial factors do not determine macroeconomic outcomes. The transition matrix has a relatively high probability of regime switching with a $H_{1,2}^{ff} = 21\%$ chance of moving from high to low financial frictions and $H_{2,1}^{ff} = 20\%$ probability of moving from a low to a high financial frictions regime.

Regarding monetary policy, when it responds strongly to the term premium, $\xi_t^{mp} = 1$, the posterior mean of the policy rule is : $ln(R_t) = 0.65ln\,(R_{t-1})+(1-0.65)\,(1.37\pi_t + 0.13y_t^{gap} - 1.16tp_t)$; meanwhile for the low response regime, $\xi_t^{mp} = 0$, we have: $ln(R_t) = 0.80ln\,(R_{t-1})+(1-0.80)\,(1.75\pi_t + 0.08y_t^{gap} - 0.24tp_t)$. As shown in figures 4 and 5, the model dynamics are different as the central bank's response to the term premium is more aggressive. The policy rules exhibit important differences across regimes in the persistence of interest rates and the relative weights on inflation and output gap. The transition matrix has a relative low probability of regime switching with a $H_{1,2}^{mp} = 9\%$ probability of moving from high to low interest rate response to the term premium and only $H_{2,1}^{mp} = 4\%$ probability of moving from a low to a high interest rate response regime.

The standard deviations of the seven shocks included in the model are allowed to change across regimes. High, medium and low volatility regimes are classified by the size of the standard deviation $\sigma_{\phi,\xi_t^{vol}}$ of the credit shocks $\varepsilon_{\phi,t}$. Remember that this shock, by increasing the interest rate spread, lowers real activity. It is noticeable that for the seven shocks the 90% confidence intervals of the high volatility regimes are larger than those of medium volatility regimes, which in turn are larger than those of low volatility regimes[15]. The probabilities of exiting a high volatility regime are $H_{1,2}^{vol} = 1\%$ to medium volatility and $H_{1,3}^{vol} = 7\%$ to low volatility. The probabilities of exiting a medium volatility regime are $H_{2,1}^{vol} = 17\%$ to high volatility and $H_{2,3}^{vol} = 19\%$ to low volatility. Finally, the probabilities of exiting a low volatility regime are $H_{3,1}^{vol} = 17\%$ to high volatility and $H_{3,2}^{vol} = 18\%$ to medium volatility.

5.2 Impulse response functions

This subsection presents the impulse response functions in response to a one-standard deviation shock to credit, σ_ϕ, and monetary policy, σ_{mp}. Appendix B shows the impulse response to a one-standard deviation shock to neutral technology, σ_a, investment-specific, σ_μ, price mark-up, σ_{mk}, wage mark-up, σ_w, and intertemporal preference, σ_{rn}. Each graph has twelve lines which depict the responses under the two alternative financial friction (H Seg. and L Seg.), the two monetary policy response to term premium (H TP Resp. and L TP Resp.), and the three credit shock volatility (H Vol., M Vol. and L Vol.) regimes. High financial frictions regimes are presented in red-like colors, while low ones are presented in blue-like colors. High monetary policy response regimes are presented in solid lines, while low ones are presented in dashed lines. High volatility regimes have the darkest colors, medium mild tones, and low ones are in the lightest tones.

Figure 4 shows the impulse response functions (IRF) of selected variables to a one-standard

[15]The only exceptions are the 90% confidence intervals for the medium and low volatility regimes for credit and monetary policy shocks, which exhibit some overlap, but the medium volatility means are larger than the low volatility ones.

deviation credit shock. An unexpected increase of the credit shock increases the 10-year bond yield and the term premium. Keeping everything else constant, the effect of this shock on the term premium is larger if the economy is in a high financial friction regime (reds) or if the interest rate response to the term premium is low (dashed). The more costly financing causes a drop of investment, with the effect being larger under high financial frictions (reds) or low interest rate response (dashed). Despite the transitory increase in output, it eventually drops with the decline being larger under high financial frictions (reds) and low interest rate response (dashed). Inflation and nominal interest rates increase more under low financial frictions (blues) and high interest rate response (solids). Obviously, the larger the volatility of the shock (darkest), the greater the amplification of the responses.

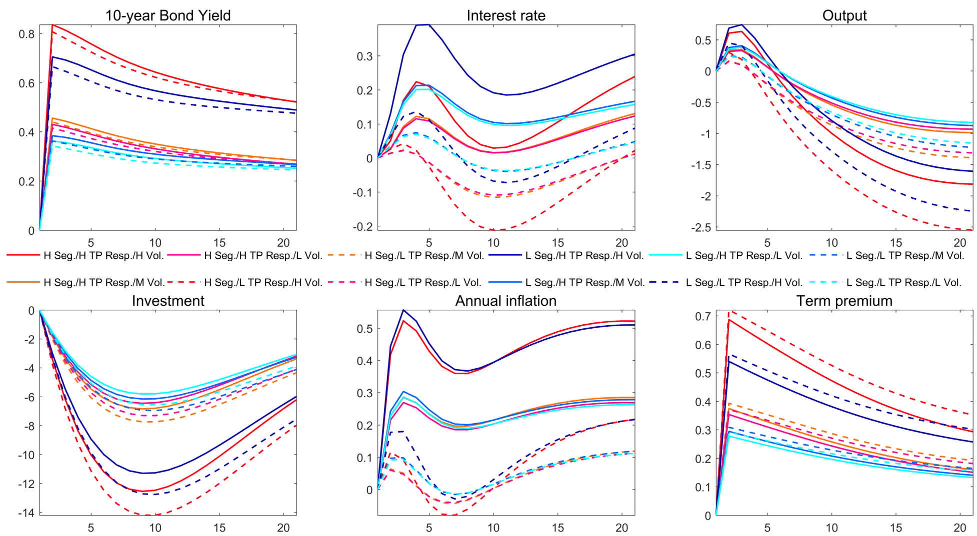

Figure 4: Impulse response functions of the MS-DSGE model to a one standard deviation credit shock under alternative regimes for financial frictions, monetary policy and volatility. High financial frictions regimes are presented in red-like colors, while low ones are presented in blue-like colors. High monetary policy response regimes are presented in solid lines, while low ones are presented in dashed lines. High volatility regimes have the darkest colors, medium mild tones, and low ones are in the lightest tones.

Figure 5 shows the impulse response functions (IRF) of selected variables to a one-standard deviation monetary policy shock. The unexpected increase lowers investment, output, and inflation, with larger drops when monetary policy has a low term premium interest rate elasticity (dashed). The term premium increase is higher when there are financial frictions (reds) and when interest rate response is low (dashed).

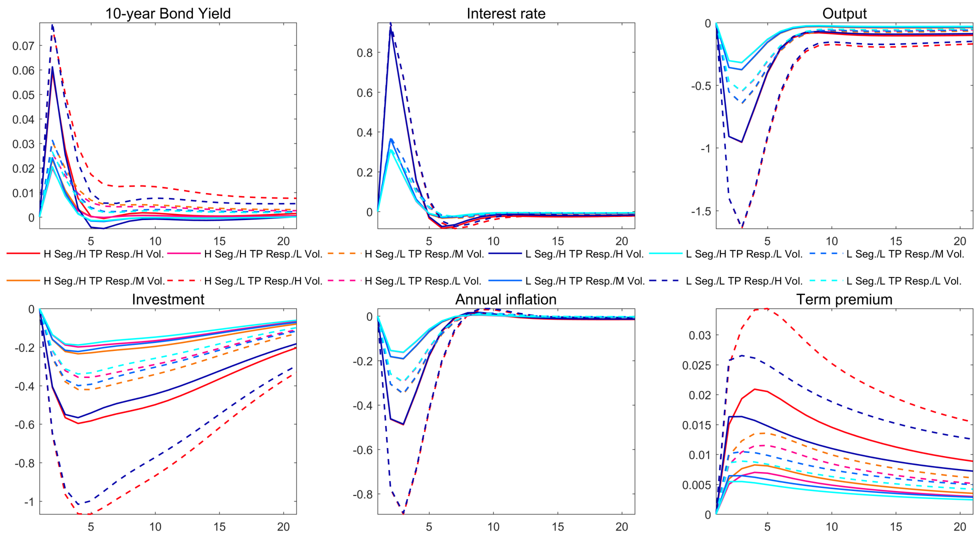

Figure 5: Impulse response functions of the MS-DSGE model to a one standard deviation monetary policy shock under alternative regimes for financial frictions, monetary policy and volatility. High financial frictions regimes are presented in red-like colors, while low ones are presented in blue-like colors. High monetary policy response regimes are presented in solid lines, while low ones are presented in dashed lines. High volatility regimes have the darkest colors, medium mild tones, and low ones are in the lightest tones.

5.3 Regime probabilities

The estimation provides us the probabilities of the high and low financial frictions and monetary policy response to the term premium regimes. Figure 6 shows the smoothed probabilities of each regime. The Bayesian Maximum Likelihood estimation of the MS-DGSE model identifies 59 quarters (27% of the sample that runs from 1962q1 to 2017q4) when financial frictions, measured by the financial intermediaries' portfolio adjustment costs to their net worth, had a large probability of being high with the following relevant intervals: 1971q1 – 1971q4, 1976q3 – 1978q3, 1983q4 – 1985q4, 1990q2 – 1991q2, 2002q3 – 2003q3, 2006q1 – 2008q1 and 2009q2 – 2010q1. Also, there are 43 quarters when the interest rate response to the term premium is estimated high with the following intervals: 1978q4 – 1983q4, 1990q2 – 1993q4 and 2010q1 – 2011q4. In addition, the MS-DSGE estimation has 34 quarters of large probability of high credit shock volatility, 46 quarters (20.6%) with large probability of medium credit shock volatility and 142 quarters (64%) with large probability of low credit shock volatility. In subsection 5.4 of counterfactual analysis we provide an historical narrative of the most representative of these regime switching episodes.

Comparing the MS-VAR and MS-DSGE there are 17 quarters (8%) which are at the same time high-stress variance and high credit shock volatility, 24 quarters (11%) that are at the same time medium-stress variance and medium credit shock volatility, and 99 quarters (45%) that are identified both as low-stress variance and low credit shock volatility states. However, from figure 7 the intersection of the two models yields 43 quarters (20%) that are identified at the same time both either medium or high-stress variance and medium and high credit shock volatility. These quarters are: 1971q1, 1973q2 – 1974q1, 1975q2 and q3, 1981q3 – 1983q4, 1993q2, 1996q4 – 1997q1, 1997q4 – 1981q1, 2003q3, 2004q1 and q2, 2008q3 and q4, 2011q3 – 2014q3, 2015q4 and 2016q2 and q3.

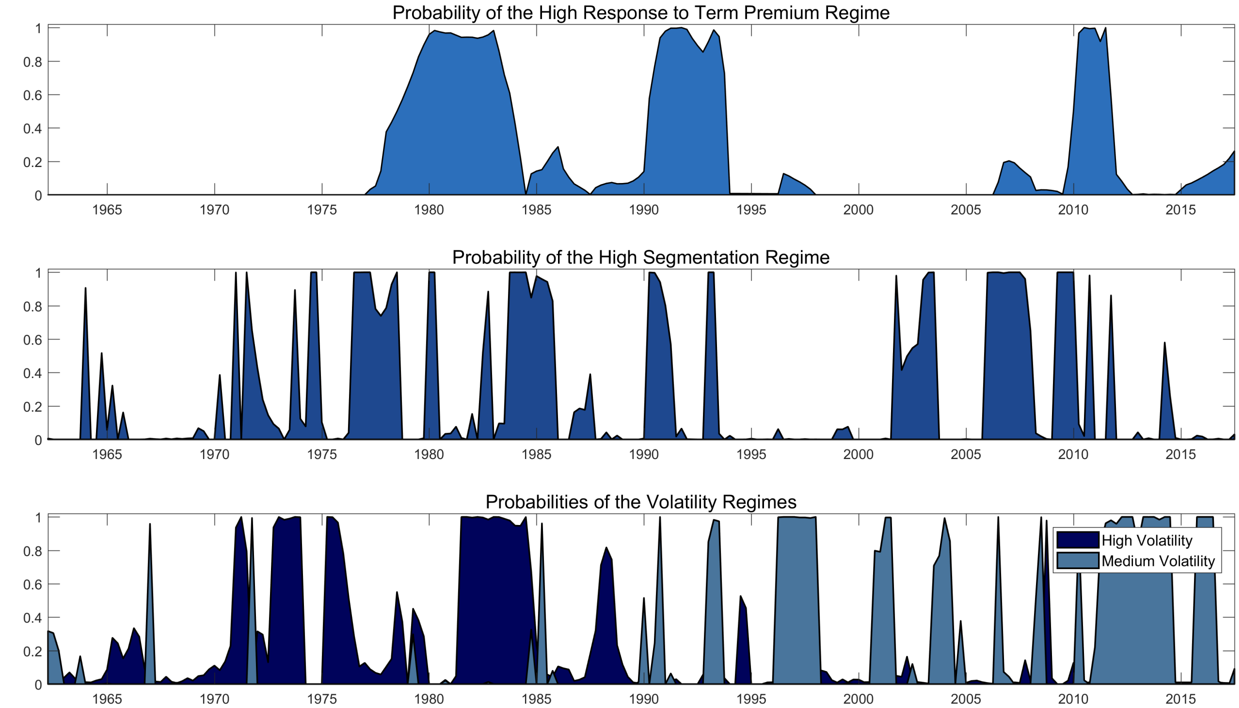

Figure 6: Regime probabilities of the MS-DSGE model at the posterior mode. Top panel: Probability of the High response to term premium regime. Middle panel: Probabilities of the High segmentation regime. Lower panel: Probabilities of the High and Medium volatility regimes.

In the next subsection we review the most relevant episodes.

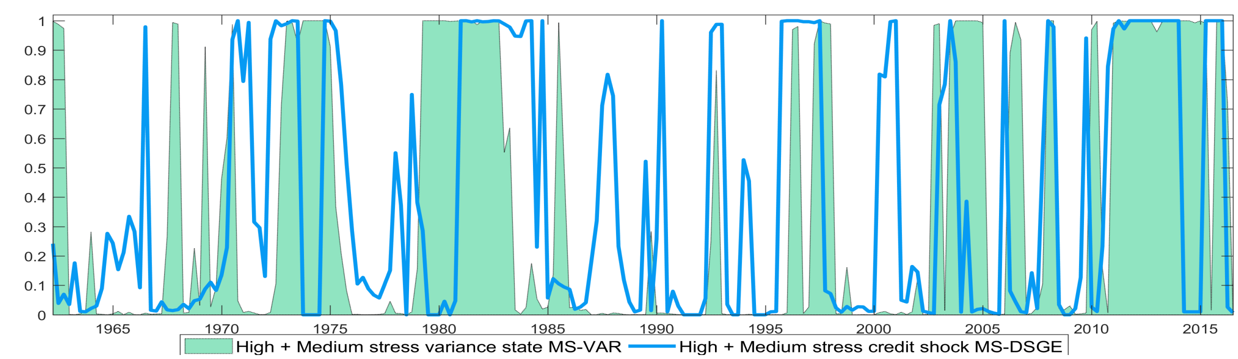

Figure 7: Comparison of MS-VAR high and medium frictions states, and MS-DSGE high and medium credit shock volatilities. The green area reports the probabilities of the High and Medium stress regime variance (as a sum) for the MS-VAR model. The blue solid line reports the probabilities of the High and Medium stress regime variance (as a sum) for the MS-DSGE model.

5.4 Counterfactual Analysis

To explore the characteristics of the MS-DSGE model with multiple parameters and variances regimes, in this exercise we generate counterfactual series based on conditional forecast simulations. Particularly, this analysis will permit us to have an idea of what could have happened if financial frictions, monetary policy regimes and volatility regimes would have remained constant, one at a time, in each of six selected episodes.

In what follows, we will examine two blocks of counterfactual simulation exercises when financial frictions and/or financial credit shocks were estimated as high or medium, which are shown chronologically in figures 8, 9, 10, 11, 13, and 12. Figures 9, 10 and 13 corresponds to the three episodes in which the monetary policy posture was responsive to the term premium in the intervals 1978q4 - 1983q4, 1990q2 - 1993q4, and 2010q1 - 2011q4, respectively. Meanwhile, figures 8, 11 and 12 are three episodes in which the interest rate response to the term premium was low. These episodes correspond to the intervals: 1971q1 - 1978q3, 2000q4 - 2004q4, and 2006q1 - 2009q4, respectively. To complement the evidence, table 5 reports the mean and standard deviation of each variable, in deviation from steady-state, under the alternative counterfactuals for the analyzed episodes.

Counterfactual figures show alternative paths where only one feature of the regime switching is allowed to change, while keeping everything else constant. Red lines compare counterfactual according to the degree of financial frictions, red solid lines show the potential evolution of the variables under high credit market segmentation, while red dashed lines reports potential evolution for the low financial frictions case. Green lines compare counterfactual according to the monetary policy response to the term premium, green solid lines show the case of high policy response and green dashed lines of low reaction. Blue lines compare counterfactual under different degrees of credit shock volatility, blue solid lines are the hypothetical behavior under high volatility, blue dashed lines report the medium volatility case, and blue dotted lines report a scenario when low credit shock volatility had prevailed during the analyzed period. The solid black line is the data in deviation from steady-state. Each figure presents 4 quarters previous to the regime switch, and conditions the fifth observation which corresponds to first quarter of the episode, say 1971q1 or 1978q4, to be the same and then let the conditional forecasts differ for each particular case, say high financial frictions while using other estimated transition matrices for monetary policy response and shocks volatility. In our attempt to determinate the role of each specific regime, we isolate the effects of the several sources of regime changes in the model[16].

[16]Following Sims and Zha (2006) and Bianchi and Ilut (2017), to isolate the effects of changes in the financial frictions mechanisms or monetary policy rules, we remove the credit shocks and monetary policy shocks in the respective simulations. In particular, for the counterfactuals that analyze changes in the monetary policy we remove the Taylor rule shock and keep the other sequence of shocks unaltered; while for the counterfactuals that examine the effects of the segmentation changes, we remove the credit shock and keep the other sequence of shocks changeless. For the counterfactuals that simulate the prevalence of the three volatility shocks, and all the sequence of shocks remain invariable.

Period	Variable		MP		Segmentation		Volatilities			
			High	Low	High	Low	High	Medium	Low	Data
1971q1-1978q3	Term premium	M	0.23	0.14	0.02	0.22	-0.07	-0.14	0.02	0.06
		SD	0.29	0.40	0.47	0.20	0.58	0.34	0.24	0.41
	Interest rate	M	0.85	1.29	1.43	0.58	1.78	0.93	0.71	1.28
		SD	1.52	1.57	1.37	1.37	1.99	1.13	0.73	1.23
	GDP growth	M	0.23	0.37	0.05	0.37	1.45	-0.01	0.49	0.24
		SD	5.23	6.39	6.31	5.97	6.78	4.71	5.26	4.56
	Inflation rate	M	2.03	2.60	3.02	1.86	3.71	2.86	2.49	2.65
		SD	2.43	2.64	2.64	2.11	3.21	2.53	1.96	2.37
1978q4 - 1983q4	Term premium	M	-0.14	-0.64	-0.29	-0.10	-0.40	-0.21	-0.13	-0.10
		SD	0.50	0.53	0.37	0.49	0.73	0.37	0.31	0.50
	Interest rate	M	6.14	7.91	7.21	6.04	9.04	6.72	5.85	5.75
		SD	1.79	2.40	1.92	2.17	2.42	2.12	2.23	2.72
	GDP growth	M	-1.10	-2.84	-1.76	-1.37	-1.21	-1.21	-0.73	-0.59
		SD	5.48	4.79	5.53	6.48	7.26	4.56	3.40	5.14
	Inflation rate	M	4.34	5.44	3.82	4.13	5.28	4.01	2.52	3.89
		SD	1.82	2.41	2.96	2.75	1.99	1.65	2.45	2.32
1990q2-1993q4	Term premium	M	0.22	0.52	-0.01	0.32	0.24	0.17	0.08	0.01
		SD	0.48	0.76	0.40	0.60	0.55	0.43	0.36	0.64
	Interest rate	M	0.15	-1.60	-0.35	0.52	0.09	0.36	0.94	0.85
		SD	1.67	2.93	2.17	1.32	2.02	1.65	1.33	2.08
	GDP growth	M	-0.10	-0.16	-0.23	-0.16	-2.01	-1.08	-1.05	-0.84
		SD	2.53	5.26	3.26	4.42	4.42	2.51	3.56	2.11
	Inflation rate	M	-0.28	-1.16	-1.03	-0.23	-1.58	-0.02	-0.36	-0.08
		SD	1.32	1.78	1.71	0.86	2.46	1.13	1.28	1.21
2000q4-2004q2	Term premium	M	-0.22	-0.17	-0.09	-0.10	0.55	-0.14	-0.06	0.24
		SD	0.39	0.37	0.32	0.26	0.73	0.33	0.45	0.50
	Interest rate	M	-1.93	-2.38	-2.20	-1.89	-4.84	-1.52	-1.50	-1.87
		SD	1.42	1.75	1.53	1.28	3.30	1.33	1.92	1.95
	GDP growth	M	-1.87	-1.64	-1.51	-1.23	-1.24	-0.76	-0.77	-0.27
		SD	4.85	4.23	3.29	3.41	5.94	2.88	3.33	2.47
	Inflation rate	M	-0.54	-2.32	-1.85	-1.43	-3.03	-1.01	-0.10	-1.35
		SD	1.62	1.19	1.48	1.69	1.96	0.93	1.39	0.92
2006q1-2009q4	Term premium	M	-0.27	-0.21	-0.30	-0.31	-0.23	-0.26	-0.37	-0.26
		SD	0.40	0.55	0.62	0.55	0.75	0.56	0.41	0.62
	Interest rate	M	-0.76	-2.24	-1.19	0.10	-0.57	-1.09	-1.59	-2.07
		SD	1.59	2.03	2.84	1.27	1.52	0.78	0.90	1.71
	GDP growth	M	-3.39	-2.72	-2.81	-1.40	-2.60	-1.82	-1.75	-2.16
		SD	4.23	4.57	3.50	2.11	4.47	1.65	2.60	3.28
	Inflation rate	M	-1.18	-0.73	-0.99	-0.33	-1.44	-1.14	-1.22	-1.14
		SD	1.66	2.86	2.28	1.80	4.02	1.38	1.26	2.40
2010q1-2011q4	Term premium	M	0.40	0.88	0.49	0.40	0.42	0.52	0.43	0.55
		SD	0.39	0.30	0.31	0.19	0.65	0.34	0.35	0.33
	Interest rate	M	-5.53	-5.70	-5.16	-5.03	-5.73	-4.99	-4.93	-4.98
		SD	0.74	0.40	0.25	0.58	0.45	0.11	0.11	0.23
	GDP growth	M	-0.97	-1.49	-0.38	0.69	-1.34	-1.29	-0.08	-2.70
		SD	2.99	2.63	2.23	1.26	3.00	1.85	1.91	3.72
	Inflation rate	M	-2.31	-3.34	-2.11	-2.05	-0.97	-1.33	-1.32	-2.21
		SD	0.98	1.42	1.04	1.03	1.76	0.90	0.76	2.55

Table 5: This table reports the mean and standard deviation of each variable, in deviation from steady-state, under the alternative counterfactuals for the analyzed episodes.

Since the start of our sample in 1962q2 and until 1971q1, the estimation assigns a high probability to a low credit market segmentation ($\psi_{n,\xi_t^{ff}=2} = 0.11$ (0.01, 0.20)) and low credit shock volatility ($\sigma_{\phi,\xi_t^{vol}=3} = 3.83$ (3.00, 4.67)) regime[17]. This despite the 1966 "Credit Crunch" and the Vietnam War expenses run by the government, the tighter monetary policy in 1967q3 and 1968q3, and that according to the NBER's Business Cycles Dating Committee there was an economic contraction from 1969q4 to 1970q4. During this period, the estimation assigns a high probability to a low interest rate response to the term premium ($\tau_{tp,\xi_t^{mp}=2} = -0.24$ (-0.36, -0.12)). Given that there is scant evidence of regime switching of either financial frictions, financial shocks or monetary policy response during this 1962q2 - 1971q1 period, we do not perform a counterfactual exercise for it.

In contrast, in the 31 quarters running from 1971q1 to 1978q3, our estimation identifies 15 quarters with high probability of credit market segmentation ($\psi_{n,\xi_t^{ff}=1} = 1.98$ with a 90% probability interval in (1.64, 2.31)) and 14 quarters of high probability of high credit shock variance ($\sigma_{\phi,\xi_t^{vol}=1} = 7.57$ (6.16, 8.97)). Despite these financial factors, in this whole period, the estimation does not provide evidence of a high interest rate response to the term premium even when the FED raised rates in 1971q3 and 1972q1 to fight inflation. It is important to keep in mind that during this period Richard Nixon's unilaterally cancelled the international convertibility of the USD to gold in 1971q3, the world economy faced the 1973q3 OPEC embargo oil shock, and the US government ran deficits to pay for the Vietnam war and President Lyndon Johnson's Great Society Programs. Also, according to the NBER's Committee there was an economic contraction from 1973q4 to 1975q1.

Figure 8 shows the first counterfactual exercise focused on this episode when as mentioned there is high probability of regime switches related to financial frictions and shocks volatility. In 1971q1, the term premium was above its steady-state level, interest rates dropped from 8.98% in December 1970 to 3.72% in February 1971, GDP growth was below steady-state and inflation was low but above steady-state. Comparing the effects of financial frictions, the red solid line of high credit market segmentation partially explains why the term premium dropped sharply, inflation rose, the interest rates increased, and output growth was smaller, relative to the red dashed line of low credit market segmentation where the term premium would had stayed closer to steady-state, there would have been a more moderate increase in inflation, interest rates would had increase less, and output growth would have been bigger than the data. Obviously there were other important domestic and external factors affecting the economy, but these factors would have been present regardless of the level of financial frictions. The opening quote in the paper by Bernanke talks about the dangerous effects of persistent deviations of the term premium from its steady state, here we see that high credit market segmentation caused these deviations to be larger and more persistent. What could have happened if the monetary authority had responded more aggressively to the term premium (solid green versus dashed green lines)? Interest rates

[17] The only exceptions are 1964q1 and 1964q4 when there is a high probability of high credit market segmentation and 1967q1 when there is a high probability of a medium credit shock variance ($\sigma_{\phi,\xi_t^{vol}=2} = 4.01$ (3.13, 4.90)).

would have remained lower during the whole episode and although inflation would have been slightly higher until 1973q2, for the remaining of the sample (1973q3 - 1978q3) it would have been on average 1% lower than with a 100% probability of high response and 1.2% lower than the data. The trade-off to this important inflation reduction is that output growth would have been lower by 0.5%. If shocks volatility have been lower (dotted blue), inflation and interest rates would have been lower and less volatile, while average output growth would have been higher than the data.

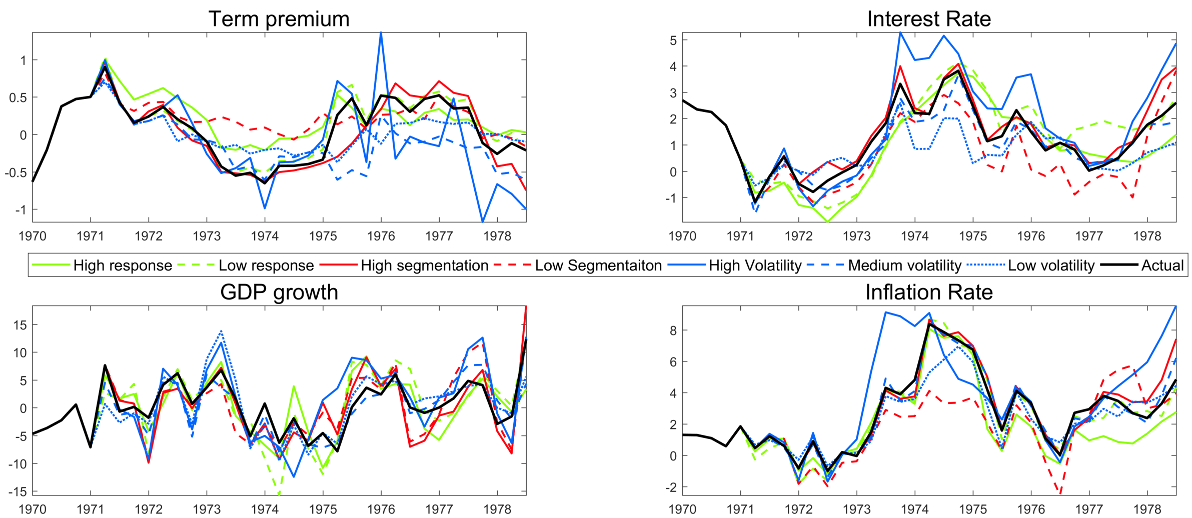

Figure 8: Counterfactual simulation from 1971q1 to 1978q3. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

Figure 9 shows the first time when our estimation assigns a high probability to a high interest rate response to the term premium ($\tau_{tp,\xi_t^{mp}=1} = -1.16$ (-1.20, -1.10)) from 1978q4 to 1983q4. In this episode, the estimation assigns a high probability to high credit market segmentation in 1980q1 and q2, 1982q3 and q4 and 1983q4. Meanwhile, the estimations assigns a high probability of a high credit shock volatility from 1981q3 to 1984q4. With inflation and interests rates rising during the late 1970s and early 1980s savings and loan institutions that had regulation on maximum interest rates that they could pay to depositors saw their funding base eroded, while the fixed-rate interest that they earned in their mortgages represented large valuation losses in their assets. Despite the Depository Institutions Deregulation and Monetary Control Act of 1980, but turned out insufficient which prompted industry deregulation and eventually taxpayers bailout.

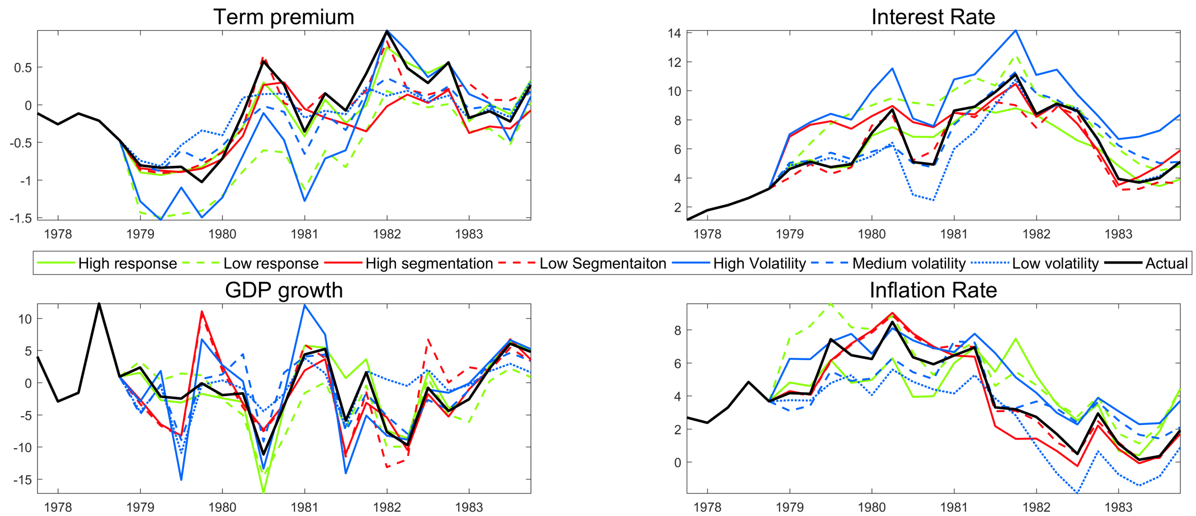

Figure 9: Counterfactual simulation from 1978q4 to 1983q4. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

The high interest rate response to term premium, which according to the estimation started 3 quarters before Paul Volcker's ascension to Fed's chairmanship, came when the term premium was below steady-state, inflation was relatively high and rising, interest rates were also rising, and GDP was above trend. In 1979q4 there was a negative oil supply shock related to the Iraq and Iran war. The NBER's committee identifies two recessions in this episode, from 1980q1 to 1980q3 and from 1981q3 to 1982q4.

What if the interest rate response had not changed (dashed green line) relative to a fully credible regime switch in monetary policy (solid green line)? With a low response interest rate, the term premium would have been much lower deviating from steady-state until 1982q1, GDP would have expanded, but at the cost of much higher inflation, which eventually would had required higher interest rates. Meanwhile, if credit shock volatility would have been lower (dotted blue), the term premium would have been closer to the steady-state level, with lower inflation and interest rates without excessive GDP fluctuations.

Figure 10 displays the counterfactual exercise for our next analyzed episode is 1990q2 to 1993q4 when interest rate response to the term premium is also estimated high with high probability. Starting in 1990q3, the FOMC lowered interest rates from 8.25% to 4% by the end of 1991 and to 3% by 1992q3. Meanwhile, the NBER' Committee dates a contraction from 1990q3 to 1991q1.

The estimation assigns a high probability to high financial frictions from 1990q2 to 1991q2 and on 1993q1 and q2, while credit shock volatility has a high probability of being of medium magnitude in 1990q4 and from 1993q1 to 1993q3. The Federal Deposits and Insurance Corporation (FDIC) experienced an improvement after president George H.W. Bush responded to the problems in the banking and thrift industries which have their origins two decades before. By the end of 1991, nearly 1,300 commercial banks either failed or required failing assistance from the FDIC causing its severe undercapitalization. The main overarching provisions of the FDICIA, which was implemented in 1994, include "prompt corrective action" and "least cost resolution. This process was followed by the Riegle-Neal Act of September 1994 that allowed banks to branch at intra- and interstate levels.

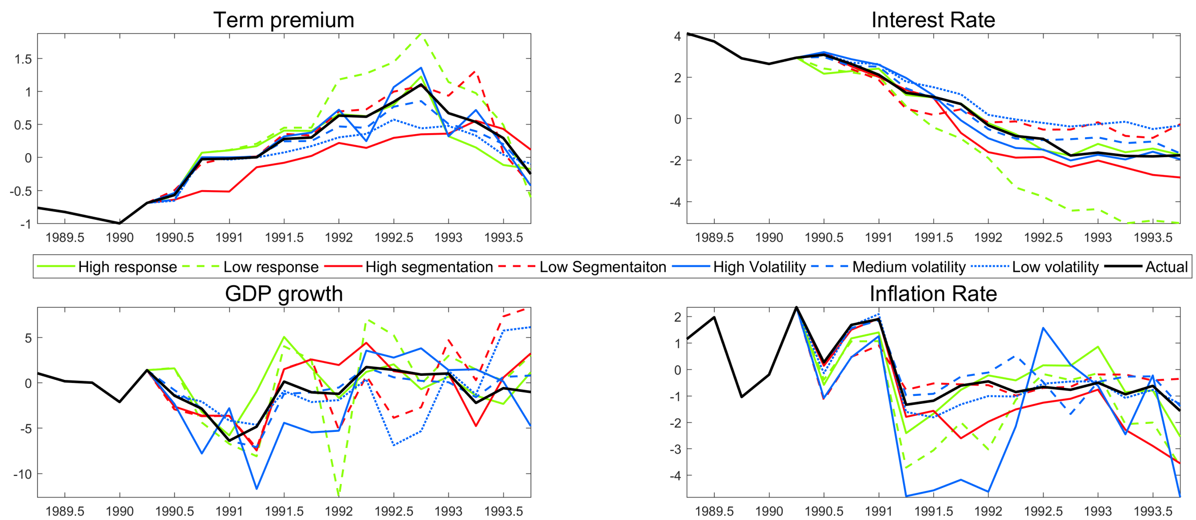

Figure 10: Counterfactual simulation from 1990q2 to 1993q4. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

In this episode, term premium was below steady-state but rose quickly. A low response to term premium (green dashed) would had implied a sharper cut in interest rates and a longer and deeper recession, while a fully-credible high response policy (green solid) would had cut interest rates less, but earlier, and could had shortened and mitigate the recession. According to the low response policy, term premium would have spiked and there could have been a huge economic contraction in 1992q1. Regarding financial frictions, it calls the attention that with higher credit market segmentation (solid red) the term premium would have raised less, interest rates would have fallen more since 1990q3 and the GDP growth recovery would have been strong until 1993q1 when the observed high financial frictions dragged GDP growth. Low shocks volatility (blue dotted) would have implied a lower term premium, and the recession would have been smaller despite less aggressive interest rate cuts, while high volatility (blue solid) would cause higher term premium and a much deeper recession.

Figure 11 shows the counterfactual exercise for our next analyzed episode is 2000q4 to 2004q2 when there is a high probability of medium credit shock volatility from 2000q4 to 2001q3 and from 2003q3 to 2004q2, and of high financial frictions in 2001q4 and from 2002q3 to 2003q3. It is important to mention that in 1999q4, president Bill Clinton signed into law the Financial Services Modernization Act, commonly called Gramm-Leach Bliley Act. This law repealed the Glass-Steagall Act and gave the Fed new supervisory powers. With this legislation, it was intended to promote the benefits of financial integration for consumers and investors while safeguarding the soundness of the banking and financial systems. Now the commercial and investment banking, separated since 1933, wouldn't have restrictions of integration between them leading to the creation of the financial holding groups (Mahon, 2013). The most common case is the merger and acquisition of Travelers Group with Citicorp, forming the nowadays well-known Citigroup. In this period the FED also played an active role as a supervisor of the Financial Holding Companies (FHC). The Fed supervises the consolidated organization, while primarily relying on the reports and supervision of the appropriate state and federal authorities for the FHC subsidiaries, taking the role of an "umbrella" supervisor. This necessity surge because these large FHC had risk spread across their subsidiaries, but managed it as a consolidated entity.

In this episode there is low probability of a high monetary policy response to the term premium. The NBER's Committee dates a contraction from 2001q1 to 2001q4 and starting in January 2001, the FOMC cut interest rates 11 times that year from 6.5% to 1.75%. Comparing the green lines we see that with a more responsive monetary policy rate, that had lowered interest rates more steeply, would have resulted in a lower term premium and it might have delayed an output contraction until 2002q3, but the contraction might have ended being more severe, while inflation would have been larger. The red dashed line provides evidence that if high financial frictions had not been present the economy would have experienced a stronger recovery since 2002q3. The solid blue line shows that if shocks had been high, the economy would have suffered a much more volatile cycle with higher term premium, much lower interest rates, greater output contraction and even a prolonged deflation.

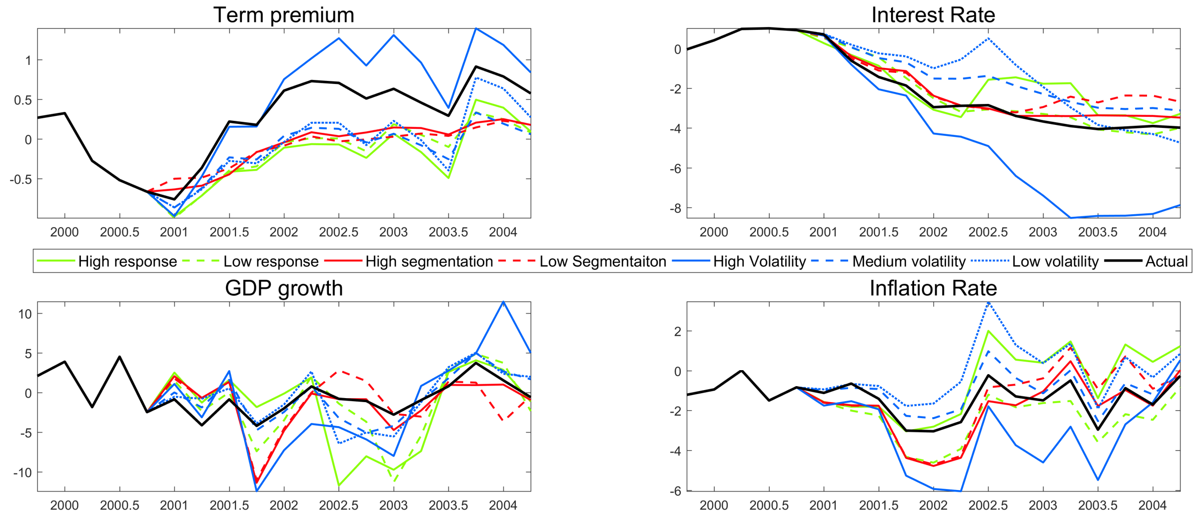

Figure 11: Counterfactual simulation from 2000q4 to 2004q2. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

Figure 12 displays the counterfactual exercise for our next analyzed episode is 2006q1 to 2009q4 when there is high probability of medium credit shock volatility in 2006q3, 2008q2 and q3 and high volatility in 2008q4, while high frictions are identified in 2006q1 - 2008q1 and 2009q2 – 2010q1. Despite being the episode directly related with our opening quote, where recently appointed Chairman Bernanke was highlighting the risks of financially stimulative declines in the term premium and the need of greater monetary policy restraint, in this episode there is low probability of a high monetary policy response to the term premium.

This episode is preceded by a Feds Funds target that in June 30, 2004 started an upward trend from the 1% prevailing since June 25, 2003 to 2.25% by the end of 2004 and 4.25% by the end of 2005. During the first half of the year the FOMC added other four 0.25% increments to 5.25% by June 2006. What could have happened if monetary policy was more responsive towards the term premium? According to the counterfactual, the solid green line shows that this would have implied rising interest rates by an additional 2%, which would have significantly slowed down economic activity. However, GDP growth did not have the large boom-bust cycle implied by a 100% probability of low monetary policy response as depicted by the dashed green line.

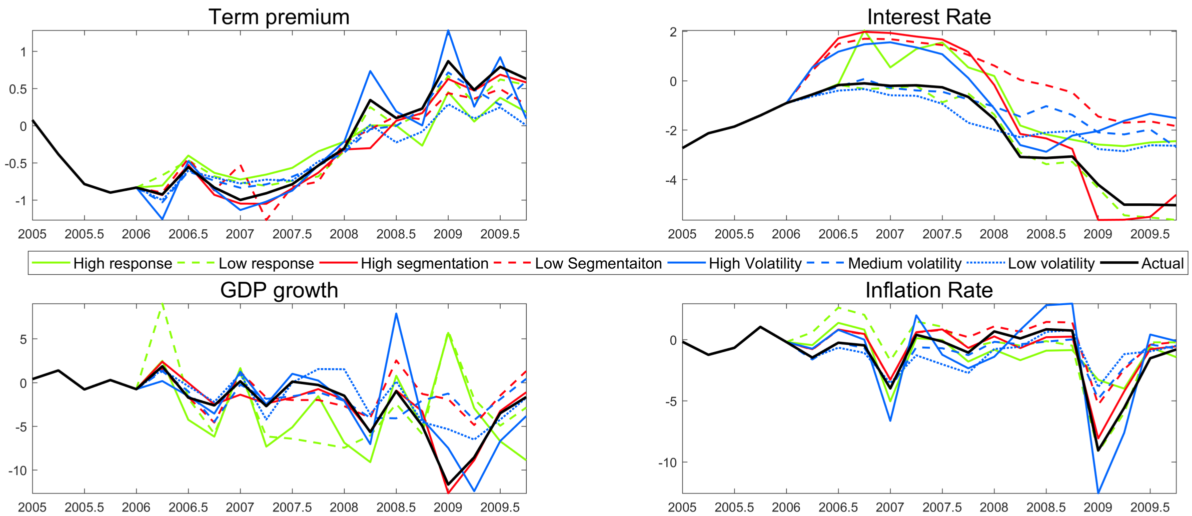

Figure 12: Counterfactual simulation from 2006q1 to 2009q4. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

The comparison of the red solid line of high financial frictions and red dashed line of low financial frictions allows us to see the important role that credit market imperfections played in the 2007q4 to 2009q2 output contraction. The presence of high financial frictions also allows us to understand why the FED needed to be so aggressive lowering interest rates during the recession lowering them to 4.25% by the end of 2007 and to [0% - 0.25%] in December 16, 2008. Meanwhile, the comparison of the three blue lines related to the magnitude of shocks volatility shows that if this had remained high in 2009q1 and q2, the output contraction would have deepened.

This period includes the most critical events of the subprime crisis. According to (Calomiris and Haber, 2014), there is no consensus among scholars, practitioners and politicians about the key causes of the subprime crisis. Some theories explaining this crisis include: the creation of new and riskier financial securities like the Mortgage Back Securities (MBS) and other financial derivatives; the excessive risk taking by Government Sponsored Enterprises (GSEs) such as Fannie Mae and Freddie Mac; and the Bush-era free market ideology. Pushing Fannie and Freddie to purchase highly leveraged risky mortgages to increase the liquidity and the capability of the lenders to extend more credits targeted to particular borrowers had huge effects on the mortgage markets. The mortgage securities market was highly unregulated. Financial indicators such as the LIBOR/OIS spread gave signs of stress and uncertainty in the U.S. economy. Rating agencies played a big role in this event. Credit ratings assigned by rating agencies affected the allocation of risk capital in the economy. Higher credit ratings allowed firms to borrow at better terms and thus positively affect a firm's value (Bae et al., 2015). After the market crash, the Federal government of the U.S. and the Fed took unprecedented actions. Fannie Mae and Freddie Mac became government owned bank after their bailout. Liquidity-support programs were designed to support the different markets in distress (Calomiris and Haber, 2014). As a measure of prevention and supervision, President Obama passed the Dodd-Frank Act to reform and regulate the banking system through the creation of a series of governmental agencies.

Figure 13 shows the counterfactual exercise for our last analyzed episode is 2010q1 to 2011q4 when there is a high probability of a high interest rate response to the term premium. Financial frictions are estimated to be high in 2010q4 and 2011q4, while medium credit shock volatility has high probability of having taken place in 2010q2 from 2011q2 to 2011q4. It is important to have in mind that the Fed Funds rate was in a zero-lower bound from December 2008 to December 2015. The economy was recovering from a recession and the term premium was above steady-state. The behavior of the term premium is followed closely by the one of high monetary policy response, high financial frictions and medium and low shocks volatility. The high interest rate response would have implied lowering interest rates by an additional 1.5% in 2010q4, which compares to an average -0.95% in 2010q4 and -1.23% in 2011 according to the Quantitative Easing (QE) adjusted shadow interest rate in Wu and Xia (Wu, Jing Cynthia and Xia, Fan Dora, Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound (May 18, 2015). Chicago Booth Research Paper No. 13-77. Available at SSRN: https://ssrn.com/abstract=2321323 or http://dx.doi.org/10.2139/ssrn.2321323). If financial frictions had been low during the entire episode GDP growth could have always been above the observed level, while if a responsive monetary policy had been fully credible GDP growth would have been also higher until 2011q2.

Aftermath the 2007-2009 crisis, president Barack Obama noticed that "the financial sector was governed by antiquated and poorly enforced rules that allowed some to take risks that endangered the economy". The US Congress, the White House and the Fed took actions to improve the actual regulation on the financial sector. By the last quarters of 2009, these authorities began their participation in the craft of the Dodd-Frank Wall Street Reform and Consumer Protection Act (Goodwing, 2013).

In 2010q1, Fed announces QE2, buying $600 billion in longer-term Treasury securities. By this time, Bernanke begins second term as Fed chairman. Also, the Dodd-Frank financial reform law becomes law and Fed issues guidelines for evaluating large BHC's capital action proposals. By 2011, the Consumer Financial Protection Bureau opens its doors, procuring the health and protection of the consumers supervising disclosure of banks, lenders and other financial companies. Around the globe, Greece admits deficit-to-GDP ratio of 12 percent (2009q4) so that IMF and the ECB run the first rescue plan and completed it 2 quarters later. By the third quarter of 2011 the European FSB cleared to purchase sovereign bonds.

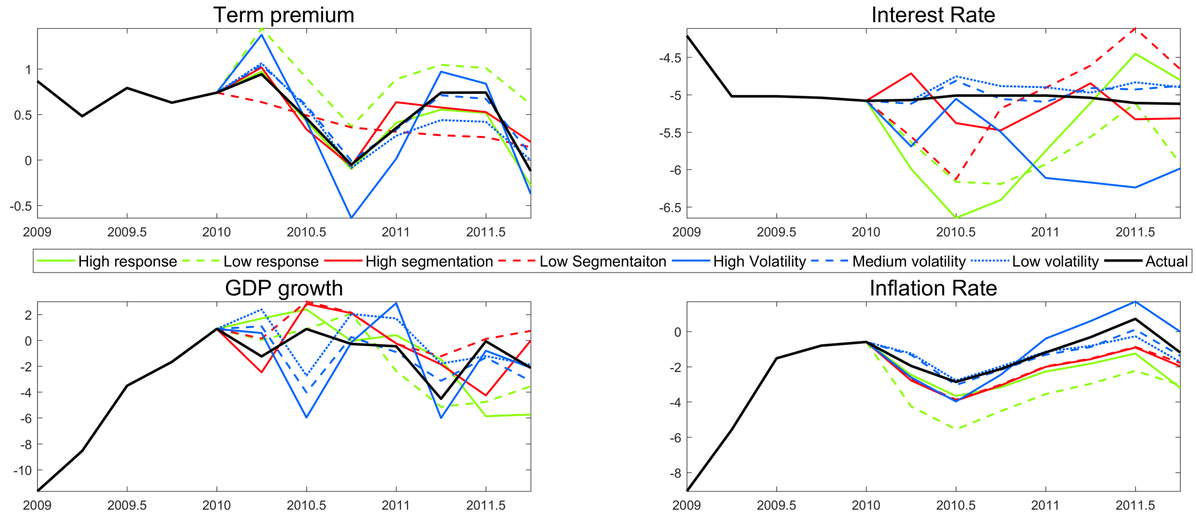

Figure 13: Counterfactual simulation from 2010q1 to 2011q4. For the counterfactuals, the solid green lines show the simulated series for the "high response to term premium" scenario; while the green dashed lines display the simulated series for the "low response to term premium" scenario. The solid red lines show the simulated series for the "high segmentation" scenario, while the dashed red lines display the "low segmentation" scenario. The solid blue lines, report the simulated series for the "high volatility" scenario; while the dashed blue lines and the dotted blue lines report the simulated series for the "medium volatility" and "low volatility" scenarios, respectively. The solid black line shows the observed series.

6 Conclusions

In this paper we use a MS-VAR to provide evidence of the importance of allowing for switching parameters (non-linearities) and switching variance (non-Gaussian) when analyzing macro-financial linkages in the US. Using the preferred specification of two regimes in coefficients and three regimes in volatilities, we modify the DSGE model in Carlstrom et al. (2017) by allowing Markov-switching in the parameters that capture financial frictions, monetary policy responses and stochastic volatility. Classifying regimes as high and low financial frictions, high and low interest rate response to term premium and high, medium and low credit shock volatility; we perform a Bayesian estimation of the model to identify those regimes. The Bayesian Maximum Likelihood estimation of the MS-DGSE model identifies 59 quarters (27% of the sample that runs from 1962q1 to 2017q4) when financial frictions, measured by the financial intermediaries' portfolio adjustment costs to their net worth, had a large probability of being high with the following relevant intervals: 1971q1 – 1971q4, 1976q3 – 1978q3, 1983q4 – 1985q4, 1990q2 – 1991q2, 2002q3 – 2003q3, 2006q1 – 2008q1 and 2009q2 – 2010q1. Also, there are 43 quarters (19.3%) when the interest rate response to the term premium is estimated high with the following intervals: 1978q4 – 1983q4, 1990q2 – 1993q4 and 2010q1 – 2011q4. In addition, the MS-DSGE estimation has 34 quarters (15.2%) of large probability of high credit shock volatility, 46 quarters (20.6%) with large probability of medium credit shock volatility and 142 quarters (63.7%) with large probability of low credit shock volatility.

We analyze six episodes when financial frictions were high and/or credit shocks volatility was either medium or high denoting disruptions in financial markets. In three of those episodes, 1978q4 - 1983q4, 1990q2 - 1993q4, and 2010q1 - 2011q4, short-term interest rates had a high response to the term premium. In the other three periods of financial distress, 1971q1 - 1978q3, 2000q4 - 2004q4, and 2006q1 - 2009q4, short-term interest rates had a low response. Counterfactual exercises allowed us to analyze what could have happened under alternative credit market conditions and monetary policy responses. These counterfactuals provide evidence of the amplifying effects of financial factors and the role that monetary policy have had mitigating financially driven business cycles.

A Model

The description in this apendix follows exactly the model description in Carlstrom et al. (2017) but allows Markov-switching in the parameters that capture financial frictions, monetary policy responses and stochastic volatility of all the shocks in the model. The economy consists of households, financial intermediaries (FIs), and firms. Many of the ingredients are standard with the chief novelty coming from their assumptions on household-FI interactions. Potential regime changes in financial frictions are captured by changes in the parameter associated to FIs' portfolio adjustment costs,ψ_n, where we use a state variable ξ_t^{ff}, to distinguish the level of financial friction regime at time t. Meanwhile regime changes in the monetary policy's response to the term premium, where we use a state variable ξ_t^{mp}, to differentiate among elasticities of short-term interest rates to the term premium τ_{tp} regime at time t. Concurrently, to allow for regime changes in the stochastic volatilities we model a third independent Markov-switching process and use a state variable ξ_t^{vol} to distinguish the volatility regime at time t.

Households

Each household maximizes the utility function

$$E_0 \sum_{s=0}^{\infty} \beta^s e^{rn_{t+s}} \left\{ ln(C_{t+s} - hC_{t+s-1}) - L\frac{H_{t+s}^{1+\eta}(j)}{1+\eta} \right\} \tag{A.1}$$

where C_t is consumption, h is the degree of habit formation, $H_t(j)$ is the labor input of household j, and e^{rn} is shock to the discount factor. This intertemporal preferences shock follows the stochastic process

$$rn_t = \rho_{rn} rn_{t-1} + \sigma_{rn,\xi_t^{vol}} \varepsilon_{rn,t} \tag{A.2}$$

where $\sigma_{rn,\xi_t^{vol}}$ is the standard deviation of the stochastic volatility of the intertemporal preferences $\varepsilon_{rn,t}$ ~ i.i.d. N(0, σ_{rn}^2), whose ξ_t^{vol} subscript denotes that it is allowed to change across regimes at time-t. We follow the same convention in the notation for each shock. Each household is a monopolistic supplier of specialized labor, $H_t(j)$, as in Erceg et al. (2000). A large number of competitive employment agencies combine this specialized labor into a homogeneous labor input sold to intermediate firms, according to

$$H_t = \left[\int_0^1 H_t(j)^{1/(1+\lambda_{w,t})} dj \right]^{1+\lambda w,t} \tag{A.3}$$

The desired markup of wages over the household's marginal rate of substitution, $\lambda_{w,t}$, follows the exogenous stochastic process of the desired markup of wages over the household's marginal rate of substitution

$$log\lambda_{w,t} = (1-\rho_w)\, log\lambda_w + \rho_w log\lambda_{w,t-1} + \sigma_{w,\xi_t^{vol}}\varepsilon_{w,t} - \theta_w \sigma_{w,\xi_t^{vo}}\varepsilon_{w,t-1} \tag{A.4}$$

with $\varepsilon_{w,t}$ *i.i.d.* N(0,σ_w^2). This is the wage markup shock. Profit maximization by the perfectly competitive employment agencies implies that the real wage (W_t) paid by intermediate firms for their homogeneous labor input is

$$W_t = \left[\int_0^1 W_t(j)^{-1/\lambda_{w,t}} dj\right]^{-\lambda_{w,t}} \tag{A.5}$$

Every period a fraction θ_w^s of households cannot freely alter their nominal wage, so their wage follow the indexation rule.

$$W_t(j) = \frac{\Pi_{t-1}^{\iota_w}}{\Pi_t} W_{t-1}(j) \tag{A.6}$$

The remaining fraction of households chooses instead an optimal real wage $W_t(j)$ by maximizing

$$E_t \left\{ \sum_{s=0}^{\infty} \theta_w^s \beta^s \left[-e^{rn_{t+s}} L \left[\frac{H_{t+s}(j)^{1+\psi}}{1+\psi} \right] + \Lambda_{t+s} W_t(j) H_{t+s}(j) \right] \right\} \tag{A.7}$$

subject to the labor demand function coming from the employment agencies, and where Λ_{t+s} is the household's marginal utility of consumption. The existence of state-contingent securities ensures that household consumption (and thus Λ_{t+s}) is the same across all households. The household also earns income by renting capital to the intermediate goods firm.

The household has two means of intertemporal smoothing: short-term deposits (D_t) in the FI and accumulation of physical capital (K_t). Households also have access to the market in short-term government bonds ("T- bills"). But since T-bills are perfect substitutes with deposits, and the supply of T- bills moves endogenously to hit the central bank's short- term interest rate target, we treat D_t as the household's net resource flow into the FIs. To introduce a need for intermediation, we assume that all investment purchases must be financed by issuing new "investment bonds" that are ultimately purchased by the FI. We find it convenient to use the perpetual bonds suggested by Woodford (2001). In particular, these bonds are perpetuities with cash flows of 1, κ, κ^2, etc. Let Q_t denote the time-t price of a new issue. Given the time pattern of the perpetuity payment, the new issue price Q_t summarizes the prices at all maturities, e.g., κQ_t is the time-t price of the perpetuity issued in period $t-1$. The duration and (gross) yield to maturity on these bonds are defined as: duration $=(1-\kappa)^{-1}$, gross yield to maturity $= Q_t^{-1} + \kappa$. Let CI_t denote the number of new perpetuities issued in time-t to finance investment. In time-t, the household's nominal liability on past issues is given by

$$F_{t-1} = CI_{t-1} + \kappa CI_{t-2} + \kappa^2 CI_{t-3} + \cdots . \tag{A.8}$$

We can use this recursion to write the new issue as

$$CI_t = (F_t - \kappa F_{t-1}) \tag{A.9}$$

The representative's households constraints are thus given by

$$C_t + \frac{D_t}{P_t} + P_t^k I_t + \frac{F_{t-1}}{P_t} \leq W_t H_t + R_t^k K_t - T_t + \frac{D_{t-1}}{P_t} R_{t-1} + \frac{Q_t \left(F_t - \kappa F_{t-1}\right)}{P_t} + div_t; \tag{A.10}$$

$$K_{t+1} \leq (1-\delta) K_t + I_t; \tag{A.11}$$

$$P_t^k I_t \leq \frac{Q_t \left(F_t - \kappa F_{t-1}\right)}{P_t} = \frac{Q_t C I_t}{P_t}, \tag{A.12}$$

where P_t is the price level; P_t^k is the real price of capital; R_{t-1} is the gross nominal interest rate on deposits; R_t^k is the real rental rate; T_t are lump-sum taxes; and div_t denotes the dividend flow from the FIs. The household also receives a profit flow from the intermediate goods producers and the new capital producers, but this is entirely standard so we dispense from this added notation for simplicity. The "loan-in-advance" constraint (A.12) will increase the private cost of purchasing investment goods. Although for simplicity we place capital accumulation within the household problem, this model formulation is isomorphic to an environment in which household-owned firms accumulate capital subject to the loan constraint. The first order conditions to the household problem include:

$$\Lambda_t = E_t \beta \Lambda_{t+1} \frac{R_t}{\Pi_{t+1}}; \tag{A.13}$$

$$\Lambda_t P_t^k M_t = E_t \beta \Lambda_{t+1} \left[R_t^k + (1-\delta) P_{t+1}^k M_{t+1} \right]; \tag{A.14}$$

$$\Lambda_t Q_t M_t = E_t \beta \Lambda_{t+1} \frac{\left[1 + \kappa Q_{t+1} M_{t+1}\right]}{\Pi_{t+1}} \tag{A.15}$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is gross inflation. Expression (A.13) is the familiar Fisher equation. The capital accumulation expression (A.14) is distorted relative to the familiar by the time- varying distortion M_t, where $M_t \equiv 1 + \frac{\vartheta_t}{\Lambda_t}$,and ϑ_t is the multiplier on the loan-in-advance constraint (A.12). The endogenous behavior of this distortion is fundamental to the real effects arising from market segmentation.

Financial Intermediaries

The FIs in the model are a stand- in for the entire financial nexus that uses accumulated net worth (N_t) and short-term liabilities (D_t) to finance investment bonds (F_t) and the long- term government bonds (B_t). The FIs are the sole buyers of the investment bonds and long-term government bonds. We again assume that government debt takes the form of Woodford-type perpetuities that provide payments of $1,\kappa,\kappa^2$ etc. Let Q_t denote the price of a new- debt issue at time-t. The time-t asset value of the current and past issues of investment bonds is

$$Q_t CI_t + \kappa Q_t[CI_{t-1} + \kappa CI_{t-2} + \kappa^2 CI_{t-3} + \cdots] = Q_t F_t \tag{A.16}$$

The FI's balance sheet is thus given by

$$\frac{B_t}{P_t}Q_t + \frac{F_t}{P_t}Q_t = \frac{D_t}{P_t} + N_t = L_t N_t \tag{A.17}$$

where L_t denotes leverage. Note that on the asset side, investment lending and long-term bond purchases are perfect substitutes to the FI. Let $R^L_{t+1} \equiv \left(\frac{1+\kappa Q_{t+1}}{Q_t}\right)$. The FI's time-$t$ profits are then given by

$$prof_t \equiv \frac{P_{t-1}}{P_t}\left[\left(R^L_t - R^d_{t-1}\right)L_{t-1} + R_{t-1}\right]N_{t-1} \tag{A.18}$$

The FI will pay out some of these profits as dividends div_t to the household, and retain the rest as net worth for subsequent activity. In making this choice the FI discounts dividends flows using the household's pricing kernel augmented with additional impatience. The FI accumulates net worth because it is subject to a financial constraint: the FI's ability to attract deposits will be limited by its net worth. We will use a simple hold- up problem to generate this leverage constraint, but a wide variety of informational restrictions will generate the same constraint. We assume that leverage is taken as given by the FI. We will return to this below. The FI's chooses dividends and net worth to solve.

$$V_t \equiv \max_{N_t, div_t} E_t \sum_{j=0}^{\infty} (\beta\zeta)^j \Lambda_{t+j} div_{t+j} \tag{A.19}$$

subject to financing constraint developed below and the following budget constraint:

$$div_t + N_t\left[1 + f(N_t)\right] \leq \frac{P_{t-1}}{P_t}\left[(R^L_t - R^d_{t-1})L_{t-1} + R^d_{t-1}\right]N_{t-1} \tag{A.20}$$

The function $f(N_t) \equiv \frac{\psi_{n,\xi^{ff}_t}}{2}(\frac{N_t - N_{ss}}{N_{ss}})$ denotes an adjustment cost function that dampens the ability of the FI to adjust the size of its portfolio in response to shocks. The ξ^{ff}_t indicates that this financial market segmentation parameter is allow to change across regime at time t. If we assumed no adjustment costs ($\psi_n = 0$) and that the net worth solution is interior, the FI's value function is linear and given by,

$$V_t = \frac{P_{t-1}}{P_t}\Lambda_t\left[(R^L_t - R^d_{t-1})L_{t-1} + R^d_{t-1}\right]N_{t-1} \equiv X_t N_{t-1} \tag{A.21}$$

But with convex adjustment cost in net worth accumulation, the FI's value function will include a time varying additive term

$$V_t = X_t N_{t-1} + g_t$$

where $g_{ss} = 0$. The term g_t is a function of aggregate variables that are exogenous to the FI

The hold-up problem work as follows. At the beginning of period $t+1$, but before aggregate shocks are realized, the FI can choose to default on its planned repayment to depositors. In this event, depositors can seize at most fraction $(1 - \Psi_t)$ of the FI's assets, where Ψ_t is a function of net worth and the other state variables. If the FI defaults, the FI is left with $\Psi_t R^L_{t+1} L_t N_t$, which it pays out to households and exits the world. To ensure that the FI will always repay the depositor, the time-t incentive compatibility constraint is thus given by

$$E_t V_{t+1} \geq \Psi_t L_t N_t E_t \Lambda_{t+1} \frac{P_t}{P_{t+1}} R^L_{t+1} \tag{A.22}$$

We will calibrate the model so that this constraint is binding in the steady state (and thus binding for small shocks around the steady state). For a fixed Ψ_t , the presence of g_t in the value function implies that leverage will typically vary with net worth, e.g., leverage will be decreasing in net worth if $E_t g_{t+1} > 0$. For simplicity, we avoid this complication by assuming that Ψ_t is a function of net worth in a manner symmetric with the convexity in the adjustment cost function. Although theoretically convenient, this assumption is quantitatively unimportant (as g_{ss}). In particular, we assume that the fraction of assets that the FI can keep in case of default is defined by

$$\Psi_t \equiv \Phi_t \left[1 + \frac{1}{N_t} \left(\frac{E_t g_{t+1}}{E_t X_{t+1}} \right) \right] \tag{A.23}$$

where Φ_t is an exogenous stochastic process that represents exogenous changes in the financial friction. For example, if $E_t g_{t+1} > 0$, assumption (A.23) implies that higher net worth makes the hold-up problem less severe. This decreased severity is chosen to counter the earlier implication that leverage would be decreasing in net worth. Assumption (A.23) implies that the binding incentive constraint (A.22) is given by

$$E_t \frac{P_t}{P_{t+1}} \Lambda_{t+1} \left[\left(\frac{R^L_{t+1}}{R^d_t} - 1 \right) L_t + 1 \right] = \Phi_t L_t E_t \Lambda_{t+1} \frac{P_t}{P_{t+1}} \frac{R^L_{t+1}}{R^d_t} \tag{A.24}$$

As anticipated, leverage is a function of aggregate variables but is independent of each FI's net worth. This implies that only aggregate net worth is needed to describe the model as all FIs are scaled versions of one another. Log-linearizing expression (A.24) we have,

$$\left(E_t r^L_{t+1} - r_t \right) = v l_t + \left[\frac{1 + L_{ss}(s-1)}{L_{ss} - 1} \right] \phi_t \tag{A.25}$$

where $v \equiv (L_{ss} - 1)^{-1}$ is the elasticity of the interest rate spread to leverage; s denotes the gross steady- state term premium, and the financial shock $\phi_t \equiv ln(\Phi_t)$ follows an AR(1) process:

$$\phi_t = (1 - \rho_\phi)\phi_{ss} + \rho_\phi \phi_{t-1} + \sigma_{\phi,\xi_t^{vol}} \varepsilon_{\phi,t} \tag{A.26}$$

Increases in ϕ_t will exacerbate the hold up problem, and thus "credit shocks", which will increase the spread and lower real activity. Qualitatively the log-linearized expression (A.25) for leverage is identical to the corresponding relationship in the more complex costly state verification (CSV) environment of, for example, Bernanke et al. (1999).

Since the incentive constraint (A.24) is now independent of net worth, the FI takes leverage as given. The FI's optimal accumulation decision is given by

$$\Lambda_t \left[1 + N_t f'(N_t) + f(N_t)\right] = E_t \beta \zeta \Lambda_{t+1} \frac{P_t}{P_{t+1}} \left[\left(R_{t+1}^L - R_t^d\right) L_t + R_t^d\right] \tag{A.27}$$

Equations (A.24) and (A.27) are fundamental to the model as they summarize the limits to arbitrage between the return on long-term bonds and the rate paid on short-term deposits. The leverage constraint (A.24) limits the FI's ability to attract deposits and thus can eliminate the arbitrage opportunity between the deposit and lending rate. Increases in net worth allow for greater arbitrage and thus can eliminate this market segmentation. Equation (A.27) limits this arbitrage in the steady-state by additional impatience ($\zeta < 1$) and dynamically by portfolio adjustment costs $\left(\psi_{n,\xi_t^{ff}} > 0\right)$. Since the FI is the sole means of investment finance, this market segmentation means that central bank purchases that alter the supply of long-term debt will have repercussions for investment loans because net worth and deposits cannot quickly sterilize the purchases.

Final Good Producers

Perfectly competitive firms produce the final consumption good Y_t combining a continuum of intermediate goods according to the CES technology:

$$Y_t = \left[\int_1^0 Y_t(i)^{1/(1+\epsilon_p)} di\right]^{1+\epsilon_p} \tag{A.28}$$

Profit maximization and the zero profit condition imply that the price of the final good, P_t, is the familiar CES aggregate of the prices of the intermediate goods.

Intermediate Goods Producers

A monopolist produces the intermediate good i according to the production function:

$$Y_t(i) = A_t K_t(i)^\alpha H_t(i)^{1-\alpha}, \tag{A.29}$$

where $K_t(i)$ and $H_t(i)$ denote the amounts of capital and labor employed by firm i. The variable lnA_t is the exogenous level of TFP and evolves according to

$$lnA_t = \rho_A lnA_{t-1} + \sigma_{a,\xi_t^{vol}} \varepsilon_{a,t} \tag{A.30}$$

Every period a fraction θ_p of intermediate firms cannot choose its price optimally, but instead resets it according to the indexation rule:

$$P_t(i) = P_{t-1}(i) \Pi_{t-1}^{\iota_p}, \tag{A.31}$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is gross inflation. The remaining fraction of firms chooses its price $P_t(i)$ optimally, by maximizing the present discounted value of future profits:

$$E_t \left\{ \sum_{s=0}^{\infty} \theta_p^s \frac{\beta^s \Lambda_{t+s}/P_{t+s}}{\Lambda_t/P_t} \left[P_t(i) \left(\prod_{k=1}^{s} \Pi_{t+k-1}^{\iota_p} \right) Y_{t+s}(i) - W_{t+s} H_{t+s}(i) - P_{t+s} R_{t+s}^k K_{t+s}(i) \right] \right\} \tag{A.32}$$

where the demand function $Y_{t+s}(i)$ comes from the final goods producers.

New Capital Producers

New capital is produced according to the production technology that takes I_t investment goods and transforms them into $\mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t$ new capital goods. The time-t profit flow is thus given by

$$P_t^k \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t - I_t, \tag{A.33}$$

where the function S captures the presence of adjustment costs in investment, as in Christiano et al. (2005), is given by $S\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\psi_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$. These firms are owned by households and discount future cash flows with Λ_t. The investment shock follows the stochastic process:

$$log\mu_t = \rho_\mu log\mu_{t-1} + \sigma_{\mu,\xi_t^{vol}} \varepsilon_{\mu,t} \tag{A.34}$$

where $\varepsilon_{\mu,t}$ is i.i.d $N(0, \sigma_\mu^2)$.

Central Bank Policy

We assume that the central bank follows a familiar Taylor rule over the short rate (T- bills and deposits):

$$ln(R_t) = \rho_{R,\xi_t^{mp}} ln(R_{t-1}) + \left(1 - \rho_{R,\xi_t^{mp}}\right) \left(\tau_{\pi,\xi_t^{mp}} \pi_t + \tau_{y,\xi_t^{mp}} y_t^{gap} + \tau_{tp,\xi_t^{mp}} tp_t\right) + \sigma_{r,\xi_t^{vol}} \epsilon_t^r \tag{A.35}$$

where $y_t^{gap} \equiv (Y_t - Y_t^f)/Y_t^f$ denotes the deviation of output from its flexible price counterpart and ϵ_t^r is an exogenous and auto-correlated policy shock with AR(1) coefficient ρ_m. The ξ_t^{mp} indicates that these parameters in the short-term interest rates rule are allowed to change across regime at time t. We will think of this as the Federal Funds Rate (FFR). We will also investigate if the central bank responds to the term premium (tp_t) into the Taylor rule. The supply of short-term bonds (T- bills) is endogenous, varying as needed to support the FFR target.

Term premium can be defined as the difference between the observed yield on a ten-year bond and the corresponding yield implied by applying the expectation hypothesis (EH) of the term structure to the series of short rates. The price of the hypothetical EH bond satisfies:

$$r_t = E_t \frac{\kappa q_{t+1}^{EH}}{R_{ss}} - q_t^{EH} \tag{A.36}$$

while it yield is given by

$$r_t^{EH,10} = \left(\frac{R_{ss} - \kappa}{R_{ss}} \right) q_t^{EH} \tag{A.37}$$

Using this definitions, the term premium can be expressed as

$$tp_t \equiv (r_t^{10} - r_t^{EH,10}) = -\left(\frac{R_{ss}^L - \kappa}{R_{ss}^L} \right) q_t + \left(\frac{R_{ss} - \kappa}{R_{ss}} \right) q_t^{EH} \tag{A.38}$$

Fiscal policy is entirely passive. Government expenditures are set to zero. Lump sum taxes move endogenously to support the interest payments on the short and long debt.

Debt Market Policy

We need one more restriction to pin down the behavior in the long-term debt. For this study, we consider one a policy regime of exogenous debt. The variable b_t denotes the real value of the long-term government debt on the balance sheet of the FIs, where $b_t \equiv ln\left(\frac{\overline{B}_t}{\overline{B}_{ss}}\right)$. This variable could fluctuate for two reasons. First, the central bank could engage in long bond purchases ("quantitative easing", or QE). Second, the fiscal authority could alter the mix of short debt to long debt in its maturity. Both of these scenarios will be modeled as exogenous movements in long debt. Under either scenario, the long yield R_t^{10} will be endogenous. To model a persistent and hump-shaped QE policy shock we will use an AR(2):

$$b_t = \rho_1^b b_{t-1} + \rho_2^b b_{t-2} + \epsilon_t^b \tag{A.39}$$

B Impulse response functions

This appendix shows the impulse response to a one-standard deviation shock to neutral technology, σ_a, investment-specific, σ_μ, price mark-up, σ_{mk}, wage mark-up, σ_w, and intertemporal preference, σ_{rn}. As described in the text, each graph has twelve lines which depict the responses under the two alternative financial friction (H Seg. and L Seg.), the two monetary policy response to term premium (H TP Resp. and L TP Resp.), and the three credit shock volatility (H Vol., M Vol. and L Vol.) regimes. High financial frictions regimes are presented in red-like colors, while low ones are presented in blue-like colors. High monetary policy response regimes are presented in solid lines, while low ones are presented in dashed lines. High volatility regimes have the darkest colors, medium mild tones, and low ones are in the lightest tones.

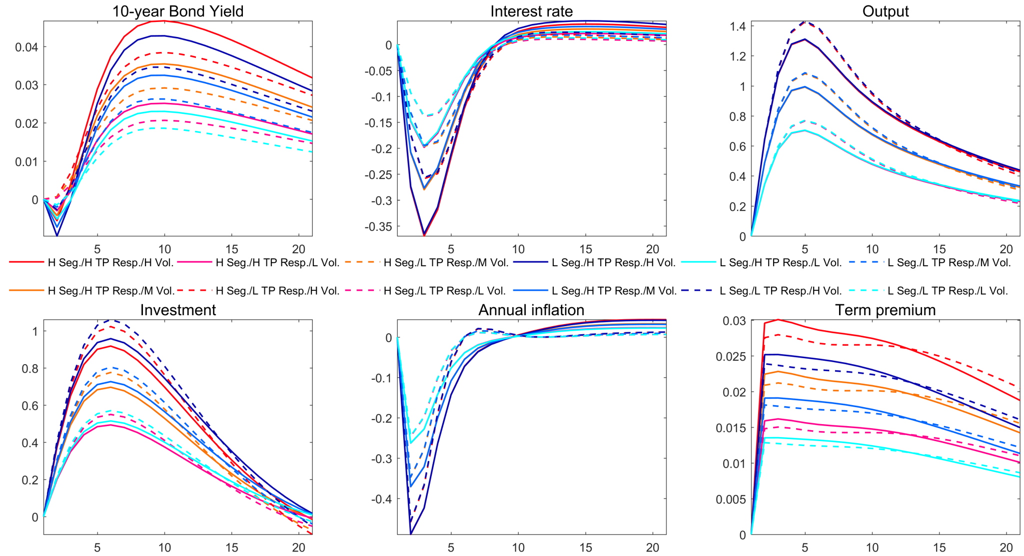

Figure 14: Impulse response functions of the MS-DSGE model to a one standard deviation neutral technology shock under alternative regimes for financial frictions, monetary policy and volatility.

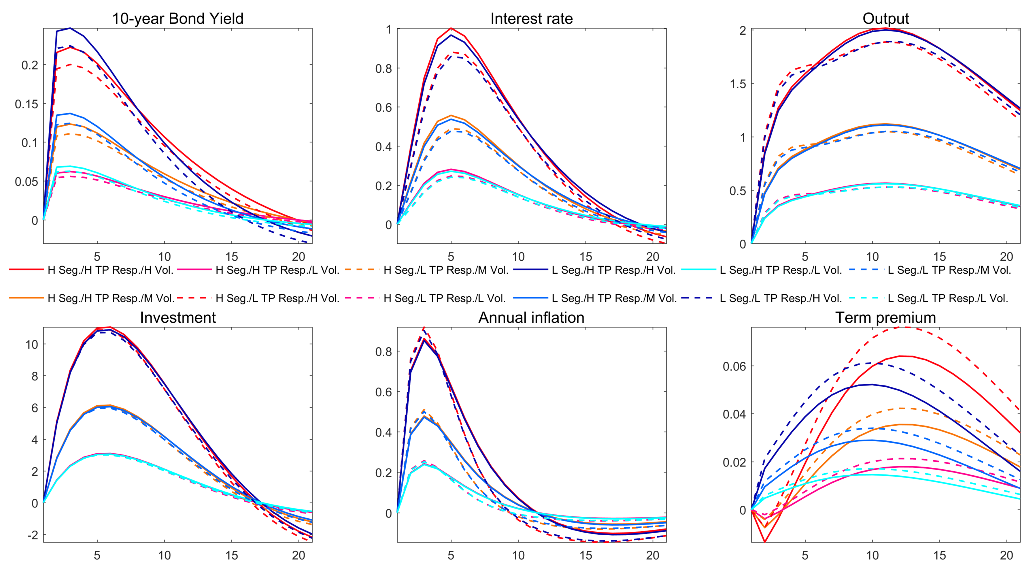

Figure 15: Impulse response functions of the MS-DSGE model to a one standard deviation investment-specific technology shock under alternative regimes for financial frictions, monetary policy and volatility.

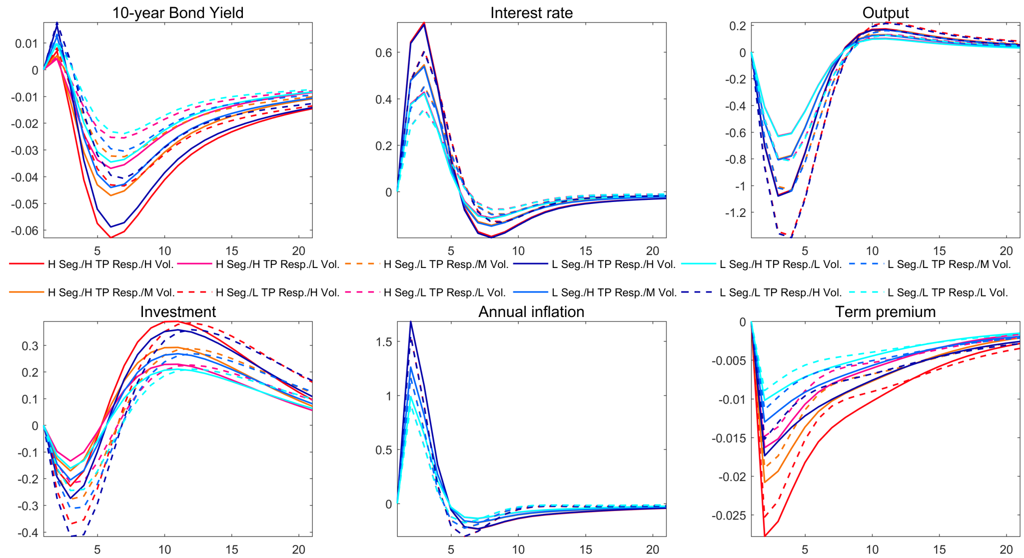

Figure 16: Impulse response functions of the MS-DSGE model to a one standard deviation price mark-up shock under alternative regimes for financial frictions, monetary policy and volatility.

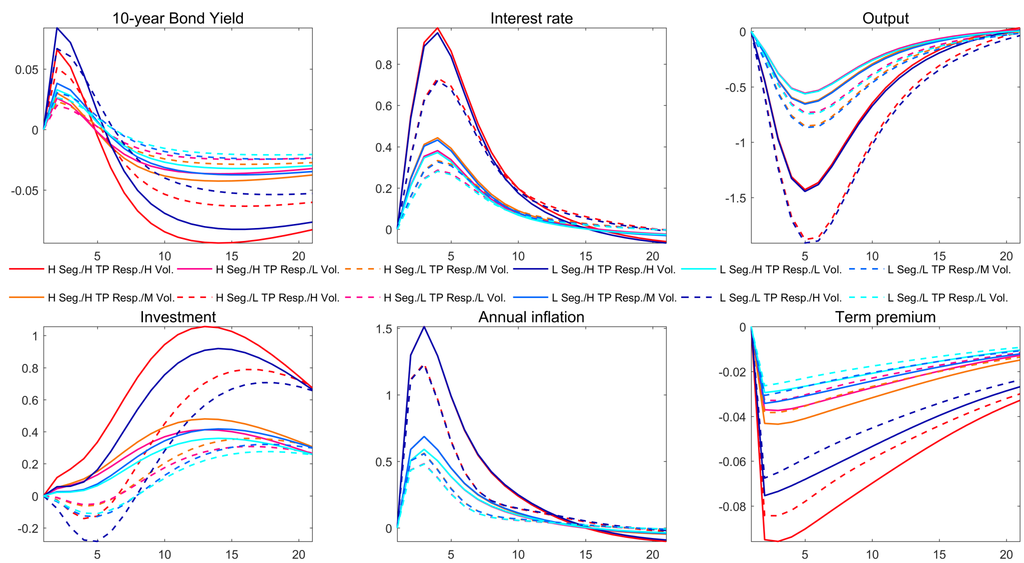

Figure 17: Impulse response functions of the MS-DSGE model to a one standard deviation wage mark-up shock under alternative regimes for financial frictions, monetary policy and volatility.

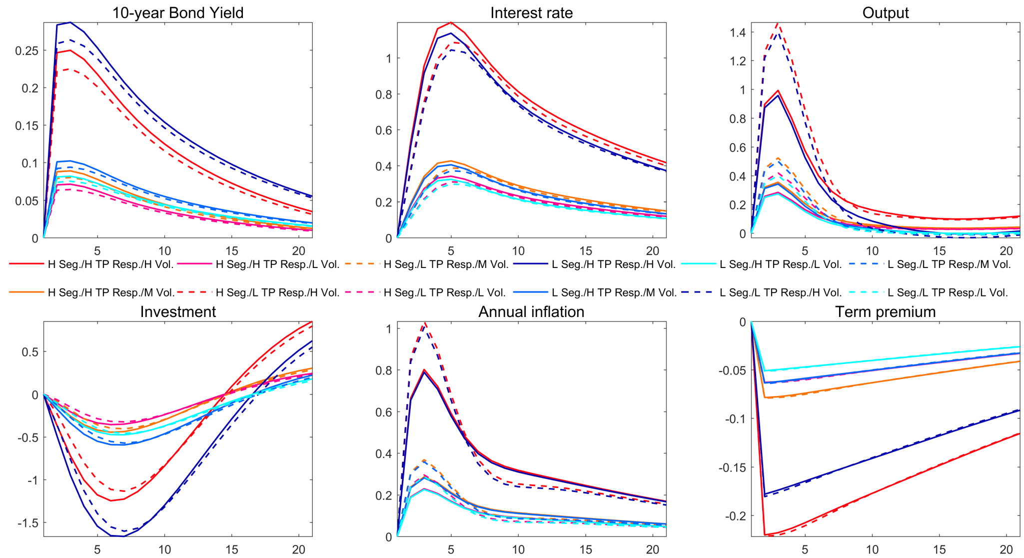

Figure 18: Impulse response functions of the MS-DSGE model to a one standard deviation intertemporal preference shock under alternative regimes for financial frictions, monetary policy and volatility.

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