Macro-Finance Essays on the Term Structure of Interest Rates

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A Thesis Submitted to the Degree of Doctor in Philosophy in Economics

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Declaration

I hereby declare that this thesis presented for examination for the PhD degree of the University of Kent is my own work other than where I have made due acknowledgement that it is the work of others.

Joseph Morell

Statement of Co-Authoured Work

I confirm that Chapter 3 of this thesis was jointly co-authoured with Dr. Katsuyuki Shibayama, Lecturer at the University of Kent and my PhD supervisor. In total, I believe that I contributed 60% of the work that went into completing this chapter.

Abstract

This thesis contributes to the literature that analyses the term structure of interest rates from a macro-finance perspective.

Chapter 1 of this thesis provides a structural interpretation behind the decline in the US term spread's predictive power with regards to future real output growth. Our analysis is conducted through use of a Dynamic Stochastic General Equilibrium New-Keynesian model that is estimated on both macroeconomic and financial data. Our findings indicate that it is changes to the composition of shocks hitting the US economy that has caused the term spread, through the endogenous monetary policy response, to cease being a useful indicator of future output growth.

Chapter 2 examines the importance of shifts in the expectations of agents in the form of "news shocks" in explaining the variation in the slope of the term structure of interest rates. The methodology employed in this chapter is a medium-scale Dynamic Stochastic General Equilibrium model that has been augmented to permit a role for both anticipated and unanticipated components in the usual array of structural shocks. In order to quantify the relative importance of each structural shock, the model is estimated via Bayesian methods on US data. We find the anticipated Total Factor Productivity shock to be quantitatively unimportant in driving US term spread fluctuations since, conditional on this shock, our model is unable to generate the observed leading procyclical movement of the spread found in the data. We do, however, find a limited role for the anticipated wage mark-up shock in that it accounts for a small share of the variation in consumption, hours and real wages.

However, it is the unanticipated shocks that account for the major share of variation in the term spread as well as other key macro aggregates.

The third and final chapter of this thesis examines the ability of the industry-standard Dynamic Stochastic General Equilibrium model to jointly explain both macroeconomic and financial data. We compute a second-order solution to our model in order to derive predictions for risk premia on equities and real, nominal and corporate bonds. Our central result is that by appending the Smets and Wouters (2007) model with Epstein-Zin preferences, long-run nominal risk and a credit market friction, we are able to generate realistic moments for the financial series under consideration without distorting the fit of our business cycle statistics.

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Preface

The term structure of interest rates may be viewed as a function that relates the rate of interest to term to maturity. The macroeconomist's view posits that the term structure is largely determined by the expected path of future short-term interest rates, which in turn are influenced by expected deviations in output and inflation from trend. Consequently, long-term bond prices are then seen to covey information that is useful for agents in formulating their savings and investment choices, but also to Central banks when formulating their monetary policy decisions.

Long-term bond prices also contain term premia which reflects the relative riskiness of investing in long-term bonds as opposed to rolling over bonds of a shorter maturity. It is typical in most macroeconomic analyses of the term structure, however, to ignore the risk-implications of long-term bond investment and restrict term premia to zero. By contrast, the finance literature is geared towards providing a statistically valid fit for bond prices across the term structure such that term premia is explicitly modelled. This is often achieved in a no-arbitrage framework that models bond yields as a linear function of a few latent factors. By definition, these latent factors are unobservable and therefore lacking in macroeconomic content. As such, the canonical finance model often precludes the ability to attribute movements in risk premiums to changes in the macroeconomic environment.

The macro-finance approach to term structure modelling seeks to overcome the issues associated with the dichotomous modelling of interest rates by adding macroeconomic content into statistically relevant term structure models. This thesis is related to a particular strand of macro-finance research that examines the bond-pricing implications of Dynamic Stochastic General Equilibrium (DSGE) models. Typically, empirical validation of DSGE models is assessed on their ability to fit macroeconomic moments, while their ability to explain key asset price facts is often overlooked. From a theoretical perspective this is problematic, since it is through asset markets in which consumption and investment are allocated across time and states of nature (Cochrane, 2005). Consequently, the need for a coherent framework that is able to simultaneously explain macroeconomic and financial data is justified on strong theoretical foundations.

This thesis is composed of three chapters, all of which model the influence of the macroeconomy on the term structure within the context of a New-Keynesian DSGE model.
The first chapter is related to those analyses exploring the predictive capacity of the term structure with regards to future real output growth. Numerous studies have found the term spread, the difference between a long and short nominal Government bond rate, to be a reliable indicator of future economic activity. In the case of the US, however, the predictive content of the term spread has diminished significantly from the mid-1980s till the present period. In light of this finding, Chapter 1 aims to provide a structural interpretation behind the decline in the US term spread's forecasting ability. The key conclusion of Chapter 1 is that it is a shift in the relative importance of shocks driving US term spread fluctuations that is the most likely explanation in accounting for the decline in its predictive power.

Expectational shocks pertaining to future improvements in Total Factor Productivity (TFP) have been found to be an important driver in the variation of the US term spread (Kurmann and Otrok, 2013*a*). Chapter 2 provides new evidence to the debate on which shocks are most important in accounting for US term spread fluctuations. To this end, we estimate a medium-scale DSGE model on US data in which the structural shocks have all been augmented to include both anticipated and unanticipated components. In general, we find the anticipated shocks to be quantitatively unimportant in driving US term spread fluctuations since, conditional on these shocks, our model is unable to generate the observed leading procylical movement of the term spread found in the data. Our model does, however, find a limited role for the anticipated wage mark-up shock in that it accounts for a small share of the variation in consumption, hours and real wages. However, it is the unanticipated shocks that account for the major share of variation in the term spread as well as other key macro aggregates.

Chapter 3 of this thesis is the result of joint work with my supervisor Dr. Katsuyuki Shibayama. In this Chapter, we examined the ability of the workhorse medium-scale model to explain both macroeconomic and financial series. So that the role of risk can be properly evaluated, we compute a second-order solution to our model in order to demonstrate how risk premia on equities and real, nominal and corporate bonds is influenced by the macroeconomy. Our central finding is that by appending the Smets and Wouters (2007) model with Epstein-Zin preferences, long-run nominal risk in the form of a time-varying inflation target and a credit market friction, we are able to generate realistic moments for the financial series under consideration without distorting the fit of our business cycle statistics.

Chapter 1

The Decline in the Predictive Power of the US Term Spread: A Structural Interpretation

1.1 Introduction

Following Burns and Mitchell (1935), macroeconomists have long recognised that spot interest rates contain useful information concerning the state of the business cycle. Short-term spot rates are predominantly influenced by the monetary authority and are set in accordance with its goals of output and inflation stabilisation. The macroeconomist's view, which assumes the expectations hypothesis[1], posits that long-term spot rates are then determined by expectations of future short-term interest rates which will in turn be influenced by expected deviations in inflation and output from trend. The information implied by the term structure, therefore, carries important practical implications, such that it is extensively monitored by policy makers and market participants when formulating their respective policy

[1]The expectations hypothesis implies that the expected excess return on long-term bonds over short-term bonds is constant over time and dependent upon maturity. In its purest form, the pure expectations hypothesis, says that these expected excess returns are zero (Lutz, 1940).

and investment choices.

Kessel (1965) documented that the gap between short and long-term spot interest rates, the term spread, tended to move with the business cycle. The authour noted that the term spread tended to narrow prior to a slowdown in economic activity and widen prior to an economic expansion. Indeed, since the inclusion of interest rate spreads in Stock and Watson (1989)'s index of leading indicators[2], studies evaluating the forecasting power of the term spread has been an active area of empirical research. The seminal contributions of Laurent et al. (1989), Chen (1991) and Estrella and Hardouvelis (1991) find evidence within a linear regression framework that the US term spread helps predict growth in real output[3]. Moreover, using a discrete-choice model, Estrella and Hardouvelis (1991) find additional evidence of the term spread to be a reliable forecaster of US recessions[4].

However, in the case of the US, the accuracy of the term spread in predicting real activity has significantly diminished from the mid-1980s (Dotsey, 1998; Estrella et al., 2003; Bordo and Haubrich, 2004, 2008). In light of this finding, this paper seeks to provide a structural interpretation behind the decline in the predictive power of the US term spread[5]. As such, our work is therefore directly related to those analyses examining the theoretical basis for the term spread's predictive power.

Our paper is most similar to Feroli (2004) in that our analysis considers a DSGE model to elucidate the procyclical nature of the term spread in terms of the structure of the economy and the functional form of Central bank's monetary reaction function. However, we differentiate our analysis by using our model to pin down an appropriate explanation among competing theories behind the term spread's structural break in predictive power. For instance, one

[2]Specifically, the authours include information on the difference between the 10 year Treasury bond rate and 3-month bill rate and the difference between the 6-month commercial paper rate and 6-month Treasury bill rate.

[3]See Plosser and Rouwenhorst (1994), Bernard and Gerlach (1998) and Estrella and Mishkin (1997) for evidence outside of the US on the term spread's ability to forecast real output.

[4]See Wheelock et al. (2009) for a comprehensive survey on the various techniques used in the literature to evaluate the predictive power of the term spread.

[5]Strictly speaking, our analysis is a model-fitting exercise in which we attempt to uncover why the empirical relation between the term spread and future rates of output growth has diminished.

contribution of our paper is to investigate whether the presence of time-varying term premia (TVTP) may have been a contributory factor behind the reduction in the term spread's predictive power. As discussed by Dewachter et al. (2014), the presence of TVTP not only invalidates the expectations hypothesis, but, in the content of macroeconomic forecasting, may potentially obfuscate the information content of the term spread. This is particularly relevant in the instance that changes in the quantity of term premia demanded by investors are less connected to future US macroeconomic developments and are more likely the result of idiosyncratic developments unique to the US bond market[6]. Of course, to properly evaluate the role of TVTP in our analysis a decomposition of the term spread is warranted. We thus use our model to decompose the term spread so that the risk-adjusted term spread can then be regressed on future output. We find, however, limited support for the TVTP explanation in that the risk-adjusted term spread is reported to be statistically insignificant in that part of our sample characterised by a loss in the term spread's leading properties.

As discussed by Bordo and Haubrich (2004), the accuracy of the spread's predictive power will also be affected by changes in the conduct of monetary policy and the structure of the economy. In order to examine if changes in these features played a role in the decline in term spread predictive power, we estimate a medium scale New-Keynesian DSGE model over two sub-samples. The first sub-sample is characterised by high predictive power in the term spread while the second sub-sample is distinguished by a loss of predictive power. We then compare our sub-sample estimates to highlight several features of both the structure of the US economy and in the operating behaviour of the Federal Reserve that may have been conducive to the high predictive power present in the first sub-sample. Our model is then used to evaluate the role of these features by generating various counterfactual paths for the term spread which are then regressed on future output. The results of our counterfactual analysis reveal that it is predominantly changes to the relative importance of shocks in ac-

[6]For example, the Global Saving Glut and increased regulatory pressures forcing pension companies to hold long-term US paper have both contributed to the recent compression in the 10 year US term premium. See Rachel and Smith (2015) for a comprehensive overview of the factors driving the secular decline in long-term interest rates.

counting for US fluctuations which, through the endogenous monetary policy response, has impaired the link between the term spread and future macroeconomic developments in recent times. Specifically, the use of a structural correlation decomposition reveals that shocks to the marginal efficiency of investment account for the dominant share of the unconditional correlation between the term spread and future output growth in that part of our sample characterised by a loss of preditive power. Conditional on this shock, we observe an instantaneous decrease in the term spread response despite positive increases in future growth rates of real output. Clearly, such responses are inconsistent with the notion that the term spread is a leading procyclical variable. In this regard, our results are therefore supportive of those papers finding the role of systematic monetary policy to be the decisive factor behind the term spread's forecasting capacity (Bernanke, 1990; Bernanke and Blinder, 1992; Smets and Tsatsaronis, 1997; Jardet, 2004; Kurmann and Otrok, 2013*a*).

The rest of this paper is structured as follows. Section 1.2 reviews the competing theories put forward to elucidate the leading properties of the term spread. In Section 1.3 we provide a rough sketch of the details of our model, leaving Section 1.4 to discuss the details of the estimation procedure. Section 1.5 then provides details on how our estimation procedure can be used to decompose the term spread. Sections 1.6 and 1.7 report and discuss the main results of our paper. Section 1.8 concludes.

1.2 Theoretical Foundations

Typically, in testing the term spread's ability to forecast the cumulative growth in future output, the extant literature has opted for estimating a linear regression of the form:

$$(400/k)\left(\ln Y^D_{t+k} - \ln Y^D_t\right) = \alpha_0 + \alpha_1 SP^D_t + \varepsilon_t \qquad (1.1)$$

where Y^D_{t+k} denotes the stock of real GDP at quarter $t+k$ and SP^D_t represents the term spread, which is constructed by subtracting the 3-month Treasury bill rate from the 10-year

Treasury bond rate. To highlight previous results we estimate (1.1) on US quarterly data spanning from 1966:1 - 2006:4. The results of this exercise are presented in Table 1.1 and are indicative of two key regularities:

(i) The sign of the estimates are consistent with the view that an increase (decrease) in the term spread implies a future expansion (slowdown) in economic activity.

(ii) The predictive capacity of the term spread is sensitive to the sample period considered. For example, the estimates obtained over the 1966:1 - 1979:2 reveal the term spread to be a reliable indicator of future output growth as evidenced by both highly significant coefficient estimates and also sizeable $\bar{R}^2$ values. The estimates reported over the 1984:1 - 2006:4 period, however, are all insignificant at the 5% level, implying a decline in the predictive power of the term spread in recent years[7].

Interestingly, despite the plethora of empirical evidence supporting these stylised facts, analyses discussing the theoretical basis for why the term spread should lead developments in output are relatively limited in comparison.

A notable exception is that of Harvey (1988) who argues that the predictive content of the term spread pertains to the real term structure. Based on a consumption-smoothing type argument, the expectation of a future recession will prompt agents to invest in long-term real bonds to ensure a pay-off in the downturn. It is the additional demand for these bonds that causes the real term spread to narrow prior to the recession, particularly if the investment is funded through selling short-term financial instruments. Of course such an explanation is problematic in that the bulk of empirical evidence concerns the nominal term structure. As argued by Benati and Goodhart (2008), the extent to which developments in the real term structure transmit through to its nominal analogue depend crucially on the stochastic properties of inflation, thereby stressing the importance of the underlying monetary regime.

[7]Indeed, the results of a Bai and Perron (1998) structural break test on (1.1) for $k = 4$ (results not reported) are supportive of a break in the empirical relationship between the term spread and future real GDP growth in 1984. Jardet (2004) also reports similar results.

Shocks under a credible regime, for example, would likely see long-term inflation expectations to remain relatively anchored and therefore less volatile in comparison to short-term inflation expectations. Consequently, the low persistence of inflation implicit under such a regime raises the potential for shifts in the nominal term spread to add noise to the predictive signals emanating from the real term spread. In their empirical analysis, however, Benati and Goodhart (2008) find limited support for the consumption-smoothing explanation. Their conclusion is based on the finding that changes in the predictive power of the US term spread do not conform with the variation in US inflation persistence as would be dictated by the consumption-smoothing explanation.

Alternatively, the other leading explanation behind the term spread's predictive power is one pertaining to the endogenous response of monetary policy. For instance, in the presence of nominal rigidities, expansionary monetary policy lowers both nominal and real rates providing stimulus for economic activity. If, in response to the monetary stimulus, agents raise their inflation expectations, then long-term interest rates will rise causing the term spread to steepen prior to the expansion in output. By a symmetric argument, a monetary tightening will see long-rates fall relatively less than short-rates causing the term spread to narrow or possibly invert prior to the contraction in real output. An implication of this theory is that (1.1) would in fact be spurious, since it is the information encoded in the short rate which is driving both subsequent output growth and the term spread. Such an assertion is routinely tested in the literature which proposes augmenting (1.1) to include some proxy of the monetary policy stance:

$$(400/k)\left(\ln Y_{t+k}^{D} - \ln Y_{t}^{D}\right) = \beta_0 + \beta_1 SP_t^D + \beta_2 FFR_t^D + \upsilon_t \tag{1.2}$$

where FFR_t^D denotes the effective federal funds rate. According to this explanation the inclusion of FFR_t^D should render β_1 statistically insignificant in (1.2). As made clear from Table 1.2, over the earlier sub-sample we observe a reduction in both the coefficient estimates and respective t statistics for β_1 relative to α_1. Moreover, we find that the β_2 is highly significant, perhaps suggestive that the short-rate was a key factor in accounting for the term spread's predictive power over this sub-sample. Over the full sample, however, we observe that β_1 retains its significance at the 5% level for all horizons and therefore casting doubt on the notion that the predictive power of the term spread is derived solely from the stance of monetary policy[8].

One interpretation of why the term spread contains additional information over and above that contained in the policy rate is that it is expectations of future monetary policy not captured by the short rate which are central to the spread's predictive power (Feroli, 2004; Estrella, 2005). The theoretical contributions of these authours stress the importance of the Central bank's objectives when evaluating the ability of the term spread to forecast output growth. For instance, the more responsive the monetary reaction function is to output deviations the better the term spread should forecast output growth. This interpretation ties in nicely with the observation that the US monetary reaction function has changed significantly since the appointment of Paul Volcker as Federal Reserve Chairman in 1979. Indeed, Clarida et al. (2000) document that the reaction function characterising the Volcker-Greenspan era has tilted in favour of a relatively greater preference for inflation stabilisation, coinciding with that part of our sample characterised by a loss of predictive power in the term spread. Finally, the presence of term premia may account for the additional forecasting power contained in the term spread. The analyses of Hamilton and Kim (2000) and Favero et al. (2005) have provided reduced form evidence that in certain sub-samples term premia positively leads real output growth. It is therefore possible that the predictive power of the spread in excess of that implied by the short rate may be coming from changes in the quantity of term premia demanded by investors.

[8] Estrella and Hardouvelis (1991), Dotsey (1998), Hamilton and Kim (2000) and Feroli (2004) reach similar conclusions.

1.3 The Model Economy

The modelling framework used in our paper borrows from the analysis of Smets and Wouters (2007)[9]. A list of the linearised equilibrium equations as well as a description of the deep parameters used in this model are presented in Tables 1.3 and 1.4 respectively. Within our framework, the predictive properties of the term spread are a natural consequence of two assumptions present in our model. First, we assume that long-term bond yields are priced in accordance with the pure expectations hypothesis[10]. Second, as is standard in closing the New-Keynesian model, we assume that the Central Bank operates in accordance with a Taylor-type rule. The respective equations are presented below.

$$r^M_{t,(n)} = \frac{1}{n} E_t \sum_{k=0}^{n-1} r^M_{t+k,(1)} \tag{1.3}$$

$$r^M_{t,(1)} = \rho_r r^M_{t-1,(1)} + (1-\rho_r)\left(\phi_\pi \pi^M_t + \phi_y \left(y^M_t - y^{f,M}_t\right)\right) + \phi_{\Delta y}\left(y^M_t - y^M_{t-1} - y^{f,M}_t + y^{f,M}_{t-1}\right) + \epsilon^r_t \tag{1.4}$$

Where $r^M_{t,(n)}$ denotes the yield on an n-period nominal bond at time t. Moreover, in the interest of clarity, we differentiate between variables obtained in the data and those variables generated by our model by using supercripts 'D' and 'M' respectively. From (1.3), the yield on a long-term bond is equal to the expected path of future short-term interest rates. Moreover, from equation (1.4), the level of the short-term interest rate is a function of the macroeconomy and will be set in accordance with the stabilisation policy employed by the Central Bank. Taken together, these equations imply that the difference between a long and short-term interest rate, the term spread, will contain the expectations of agents pricing in their expected paths for future inflation and output over the relevant horizon.

[9] For more details, the reader is referred to their original paper and the accompanying appendix to this paper which can be downloaded from the authour's website.

[10] As discussed by Schmitt-Grohé and Uribe (2004), a first-order approximation of our model requires the certainty equivalence principle to hold in order to ensure a unique solution. Term premia is therefore restricted to zero since, in expectation, all asset prices will be equalised which thus implies the pure expectations hypothesis.

1.4 Estimation Procedure

Prior to the estimation our model, we calibrate a subset of parameters that are notoriously difficult to identify in the literature. In particular, we set the rate of capital depreciation, δ, to 0.025, implying an annual depreciation rate of 10%. We fix the steady state wage mark-up, ϕ_w, to 1.5 and the steady state Govt' spending-output ratio to 0.18. Finally, we fix the curvature of the Kimball goods market aggregator, ϵ_p, and the Kimball labour market aggregator, ϵ_w, to both 10. The rest of the model's parameters are estimated on the following vector of observables:

$$\mathbf{Y_t} = \begin{bmatrix} \Delta \ln \mathrm{CONS}_t \\ \Delta \ln \mathrm{GDP}_t \\ \Delta \ln \mathrm{WAG}_t \\ \Delta \ln \mathrm{INV}_t \\ \ln \mathrm{HOURS}_t \\ \mathrm{INF}_t \\ \mathrm{FEDFUNDS}_t \\ \mathrm{TERMSPREAD}_t \end{bmatrix}$$

In keeping with Smets and Wouters (2007), we include information on: the log difference of real consumption, the log difference of real output, the log difference of real wages, the log difference of real investment, the log of hours worked, the log difference of the GDP deflator and the federal funds rate. A key addition to our model is that we also include the term spread in the measurement equation, which we construct by taking the difference between the 10-year Treasury bond rate and the 3-month Treasury bill rate. In a similar vein to Smets and Wouters (2007), we estimate our model over a full sample period from 1964:1 - 2006:4, and then subsequently over two sub-sample periods: 1964:1 - 1979:2 and 1982:1 - 2006:4. The sub-sample estimations are motivated on the basis that there is a marked difference in the predictive power of the term spread between these two periods. Comparison of parameter estimates, therefore, will identify potential explanations for the instability in the term spread's predictive power. The measurement equation in which we map our vector of observables to their model counterparts are presented below:

$$\mathbf{Y_t}' = \begin{bmatrix} \Delta \ln \mathrm{CONS}_t \\ \Delta \ln \mathrm{GDP}_t \\ \Delta \ln \mathrm{WAG}_t \\ \Delta \ln \mathrm{INV}_t \\ \ln \mathrm{HOURS}_t \\ \mathrm{INF}_t \\ \mathrm{FEDFUNDS}_t \\ \mathrm{TERMSPREAD}_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{r} \\ \bar{\mathfrak{c}} \end{bmatrix} + \begin{bmatrix} c_t^M - c_{t-1}^M \\ y_t^M - y_{t-1}^M \\ w_t^M - w_{t-1}^M \\ i_t^M - i_{t-1}^M \\ l_t^M \\ \pi_t^M \\ r_{t,(1)}^M \\ r_{t,(40)}^M - r_{t,(1)}^M \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \eta_t^m \end{bmatrix} \tag{1.5}$$

where $\bar{\gamma} = 100 \cdot (\gamma - 1)$ denotes the trend growth rate of the economy, $\bar{l}$ is the steady state of hours worked, $\bar{\pi} = 100 \cdot (\Pi - 1)$ represents the steady state rate of inflation, $\bar{r} = 100 \cdot (\gamma^{\sigma_c}\beta^{-1}\Pi - 1)$ represents the steady state nominal interest rate and $\bar{\mathfrak{c}}$ denotes the level of the term spread in steady state. Furthermore, we attach a measurement error, η_t^m, onto the measurement equation associated with the term spread, the motivation for doing so is discussed in greater detail in the subsequent section.

Given that the model used in our analysis is a close variant of the Smets and Wouters (2007) model, our prior elicitation strategy also follows the one employed in their paper. As such, we refer the reader to Smets and Wouters (2007) for a comprehensive review of the prior elicitation strategy used in both papers. One parameter, however, that is absent from Smets and Wouters (2007)'s analysis is the constant that governs the term spread in the steady state, $\bar{\mathfrak{c}}$. We assume that the prior for this parameter is normally distributed with a mean 0.25 and a standard error 0.10,

As to be expected, our full sample estimates, presented in Table 1.4, are similar to those reported in the original Smets and Wouters (2007) paper. Any differences between our estimates may be attributed to the extended data series and the addition of the term spread in the measurement equation. Moreover, from Figure 1.1, our estimation results reveal that all parameters are identified by our data set. Comparing the estimates between the two sub-samples reveals a number of significant observations:

(i) The variances of the exogenous shocks, excluding the wage mark-up shock, appear to have fallen in the second sub-sample, suggesting that the composition of shocks hitting the economy has changed between the two sub-samples.

(ii) We also report an increase in the variance of the measurement error in the second sub-sample, indicative of a worsening in model fit for the term spread over this period.

(iii) The monetary reaction coefficients also appear to differ between the two sub-samples. For example, the latter sub-sample is characterised by a greater emphasis on stabilising inflation deviations relative to stabilising deviations in output. In this regard, our findings are supportive of, among others, Judd and Rudebusch (1998), Taylor (1999), Clarida et al. (2000) and Cogley and Sargent (2005) who find significant time variation in the monetary policy rule employed by the Federal Reserve. Indeed, these authours estimate the monetary policy rules of Fed chairmen Paul Volcker (1979Q3 - 1987Q2) and Alan Greenspan (1987Q3 - 2006Q1) to be considerably more aggressive in their responses to inflation than that of the rule estimated under Arthur Burns (1970Q1 - 1978Q1). We do, however, report similar estimates for the interest rate smoothing parameter, ρ_r, over the two sub-samples.

(iv) A final observation is that the slope of the New-Keynesian Phillips curve (NKPC) is estimated to be flatter in the latter sub-sample[11].

[11] See Kuttner and Robinson (2010) for an overview of the possible explanations behind the flattening of the Phillips curve.

1.5 Decomposing the Term Spread

The discussion so far attributes the term spread's predictive power to the information content implicit in the expected path of future short-term interest rates. Practically, this is problematic in that it is conditional on the basis that the expectations hypothesis is supported empirically. Notable contributions from Fama and Bliss (1987) and Campbell and Shiller (1991), however, have rejected the expectations hypothesis in favour of finding time-varying term premia which may distort the information content contained in the term spread. It is therefore appropriate to use our model to decompose the term spread into these two components as demonstrated in the equation below.

$$r^D_{t,(40)} - r^D_{t,(1)} = \left(\frac{1}{40}\sum_{k=0}^{39} E_t\left\{r^M_{t+k,(1)}\right\} - r^M_{t,(1)}\right) + \left(r^M_{t,(40)} - \frac{1}{40}\sum_{k=0}^{39} E_t\left\{r^M_{t+k,(1)}\right\}\right) \tag{1.6}$$

The first term on the RHS of (1.6) is consistent with the expectations hypothesis and reflects the market's views on the future path of the short-term interest rate. The second term denotes term premia which reflects investors' views on the relative riskiness of investing in long-term bonds. From (1.3), it follows that the second term on the RHS of (1.6) is equal to zero as is consistent with the pure expectations hypothesis. A decomposition of the term spread is therefore necessary to isolate the component pertaining to changes in expectations. In what follows, we provide an overview of how our methodology provides a convenient way of decomposing the term spread.

By construction, the pure expectations hypothesis is a natural implication of estimating a first-order approximation of our model. The smoothed estimate of the term spread generated by our model will therefore be driven exclusively by changes in the expected path of the policy rate[12]. Conversely, those term spread fluctuations in the data that our model is

[12] A pertinent point raised by De Graeve et al. (2009) is that a rigorous representation of the economy is required in order to accurately price the expectational component of the term spread. The use of the Smets and Wouters (2007) model in our analysis seems suitable in this regard since it has been shown to forecast

unable to account for will be reflected through the variance of the measurement error which, in principle, should serve as a proxy for term premia. The decomposition of the 10 year term spread implied by our model will therefore be of the form:

$$r^D_{t,(40)} - r^D_{t,(1)} = \left(\frac{1}{40} \sum_{k=0}^{39} E_t \left\{ r^M_{t+k,(1)} \right\} - r^M_{t,(1)} \right) + \eta^m_t \tag{1.7}$$

To assess the validity of our decomposition technique, Figure 1.2 plots the time series estimate of our measurement error alongside alternative estimates of the 10 year term premium commonly quoted in the literature[13].

Inspection of Figure 1.2 reveals that the measurement error does capture the salient features of these alternative series. Indeed, further evidence of co-movement is presented in Table 1.6, where the first column reports the correlation coefficients between the measurement error and the alternative series. Reassuringly, we report high correlation coefficients over our sample ranging from 0.74 to 0.84[14]. Moreover, when the sample is split from 1982 onwards, reflecting that period in which the term spread has lost predictive power, the correlation coefficients all increase. Although rudimentary, Figure 1.2 and Table 1.6 provide some evidence that our decomposition method is in keeping with other techniques and therefore seems suitable for our point of analysis.

key macroeconomic series to a similar standard to that of Bayesian vector autoregression (BVAR).

[13]The "VAR" estimate of the term premium is based on a trivariate vector autorgression (VAR) comprised of the unemployment rate, the inflation rate and the three-month Treasury bill rate. The VAR is then used to project an estimate of the risk-neutral long rate. The term premium is then calculated by subtracting the VAR-based risk neutral rate from the observed rate. Our method follows a similar approach to the VAR measure in that we also use our model to project forward an estimate of risk-neutral long rate. The measurement error in our analysis is used to capture the difference between the risk-neutral rate and the observed long-term rate. This may explain why our measure and the VAR measure are highly correlated due to the similarity in approaches. However, relative to the atheoretical VAR measure, our estimate of the risk-neutral long rate is obtained under explicit optimisation of the consumption-Euler equation. The term premium estimates of both the "KW" and "CP" measures are obtained using affine term structure models. Under these class of models, the term premium is determined by latent factors which, by definition, lack economic interpretation.

[14]Principal component analysis reveals that the first principal component, denoted by λ_1 in Table 1.6, captures 95% of the variation in these three other estimates and is therefore representative of developments in the 10 year term premium more generally. We take further confidence in the finding that the correlation between our measurement error and the first principal component is 0.83.

1.6 Regression Analysis

1.6.1 Time-Varying Term Premia

A key observation from Table 1.5 is that our proxy for term premia, the measurement error, is relatively more volatile in the latter part of the sample[15]. This may also be interpreted as a decline in the extent to which the expectations hypothesis can account for term spread fluctuations in the data over this sub-sample. This, however, is problematic for our investigation in that the theoretical basis of why the spread leads output growth pertains to the expectational component. Furthermore, since there is no reason to suspect that the reduced form evidence showing term premia to lead output growth to remain stable over time, then any instability in this relationship may ultimately cause developments in term premia to obfuscate the forecasting power of the spread. In this sub-section, we investigate whether the presence of time-varying term premia may have been a contributory factor behind the decline in the predictive power of the term spread. To this end, we regress the cumulative growth rate of future real GDP on both components of the 10 year term spread[16]:

$$(400/k)\left(\ln Y^D_{t+k} - \ln Y^D_t\right) = \gamma_0 + \gamma_1 \left(\frac{1}{40} \sum_{k=0}^{39} E_t \left\{ r^M_{t+k,(1)} \right\} - r^M_{t,(1)} \right) + \gamma_2 \eta^m_t + \upsilon_t \tag{1.8}$$

Table 1.7 contains the results of this exercise which, for comparative purposes, are presented alongside the estimates obtained for equation (1.1). Focussing first on the earlier sub-sample, a number of observations are worth discussing. First, and perhaps to be expected, we report higher t-statistics for the expectational component, γ_1, relative to the raw term spread coefficient, α_1, reflecting greater significance in these estimates. It is, however, interesting to note that the size of the coefficient estimates of γ_1 are strikingly similar to α_1 at all forecasting horizons. Second, and complimentary to the findings of Hamilton and Kim (2000) and Favero et al. (2005), we report statistically significant and positive coefficient estimates for the

[15]The standard deviation of the measurement error is denoted by σ_m.
[16]For consistency, we use the same real GDP series as that used in estimating (1).

term premia component.[17] Third, the results of a Wald test indicate that the contributions of the expectational and term premia components are indeed statistically different from one another.[18] Moreover, we can conclude that it is the contribution of the expectational component that is the most important factor in predicting future output growth, since we report both higher coefficient estimates and respective t-statistics for γ_1 relative to γ_2. In this regard, our results support the findings of Rudebusch et al. (2007) and Rosenberg and Maurer (2008).

For the later sub-sample, our results indicate that, in spite of decomposing the term spread, the expectational component is statistically insignificant. We report similar findings for the term premia component, although it is found to be marginally significant for a forecasting horizon of 2,6 and 8 quarters. Our findings for this sub-sample suggest that the presence of term premia has not been blurring the information content of the term spread and therefore cannot account for the decline in predictive power.

1.6.2 Counterfactual Analysis

In this section, we use counterfactual analysis to test if the instability in certain sub-sets of parameters may be able to account for the term spread's poor forecasting power over the latter sub-sample. We perform all our counterfactual simulations through use of DYNARE's 'simult' function:

$$ts_i = \text{simult}\left(\bar{y}, dr_i, x\right) \tag{1.9}$$

As inputs to the function we provide the decision rules of a calibrated model, dr_i, a shock matrix for which the model is simulated on, x, and a vector of initial values for which to begin the simulation, $\bar{y}$. As an output, the function will return the time series of an endogenous variable which, in the interest of our analysis, will be the expectational component of the

[17] Although we report marginal significance in the case of k = 2 and k = 8.

[18] Hamilton and Kim (2000) also report similar findings.

term spread, ts_i. Furthermore, the subscript i references the counterfactual experiment. For comparative purposes, we define the benchmark case as the expectational component generated by using a model calibrated to the first sub-sample mode estimates, simulated on the first sub-sample smoothed shock estimates. Motivated by the results of our sub-sample estimations, we then attempt to account for the fall in predictive power by changing certain sub-sets of parameters in our benchmark model. We then simulate our model and subsequently regress the respective expectational component on future real GDP growth as before:

$$(400/k)\left(\ln Y_{t+k} - \ln Y_t\right) = \alpha_{0,i} + \alpha_{1,i} ts_i + \varepsilon_{t,i} \tag{1.10}$$

A key finding from Table 1.5 is that the monetary reaction coefficients appear to differ between the two sub-samples. Specifically, the latter sub-sample is characterised by a greater emphasis on stabilising inflation deviations relative to stabilising deviations in output which, as discussed, is a finding that has been well documented for the Federal reserve. Our analysis, however, is concerned with the implications for the spread's predictive power in light of changes to the monetary policy rule. The motivation for such an experiment is based on the theoretical contributions of Feroli (2004) and Estrella (2005). These authours discuss how the predictive signals provided by the term spread should become more accurate as the Central bank becomes increasingly sensitive to output deviations when formulating policy. Our sub-sample estimates are consistent with this prediction in that we estimate a reaction function that has become relatively less sensitive to output deviations in that part of our sample characterised by a loss of predictive power. To examine whether the change in the monetary policy rule can account for the decline in predictive power, we change only the monetary reaction coefficients in our benchmark calibrated model to the estimates obtained in the second sub-sample. From Table 1.8, relative to the benchmark model, it seems that in spite of allowing for the shift in Fed operating behaviour, the expectational component remains statistically significant. Therefore, our reduced-form evidence leads us to conclude that the change in the monetary policy rule alone is not able to account for the decline in predictive power. We do, however, report lower adjusted R-squared values under a reaction function characterised by a relatively greater sensitivity to inflation deviations at all forecasting horizons. Our results are therefore suggestive that the monetary policy rule is a factor in influencing the spread's predictive power and thus provides some empirical support for the analyses of Feroli (2004) and Estrella (2005).

A second observation from our sub-sample estimates is that the slope of the NKPC is estimated to be flatter in the latter sub-sample. While the extant literature exhibits a conflicting set of results over the time variation in the Phillips curve slope,[19] our finding is at least consistent with several notable analyses[20] (Atkeson and Ohanian, 2001; Staiger et al., 2001; Roberts, 2006; Kuttner and Robinson, 2010). The implication of a flatter NKPC slope is that for a given deviation in output we observe less transmission through to inflation. Therefore, there is a case that a flatter NKPC slope, coupled with a greater weight on inflation in the Fed's reaction function may reduce the predictive power of the term spread. We test this by changing only the relevant slope parameter values in our benchmark model to those estimates obtained in the second sub-sample. Table 1.9 presents the reduced-form evidence from this simulation. Our results make clear that the change in the slope of the NKPC is not able to account for the decline in predictive power, since the respective expectational component remains statistically significant. We do, however, report lower adjusted R-squared values under a flatter NKPC slope at all forecasting horizons.

A final observation from our sub-sample estimates is that the variances of the exogenous shocks, excluding the wage mark-up shock, appear to have fallen in the second sub-sample[21], suggesting that the composition of shocks hitting the US economy has changed between the two sub-samples. Such a result warrants further investigation upon consideration of the numerous studies that have posited the importance of systematic monetary policy in ex-

[19] See, for example, Fitzgerald et al. (2013) who discusses how the variety of functional forms for the Phillips curve, the data used in its estimation and the horizon for which future inflation is considered, all contribute to the wide estimates of the time variation in the slope.

[20] See Kuttner and Robinson (2010) for an overview of the possible explanations behind the flattening of the US Phillips curve.

[21] Similar findings are also reported in Smets and Wouters (2007).

plaining the term spread's predictive power (Bernanke, 1990; Estrella and Hardouvelis, 1991; Bernanke and Blinder, 1992; Smets and Tsatsaronis, 1997; Dotsey, 1998; Jardet, 2004; Kurmann and Otrok, 2013*a*). This is because any changes to the relative importance of shocks driving US business-cycle fluctuations will imply different policy responses that may or may not result in a term spread that positively leads output growth. We investigate whether changes to the US shock composition can account for the decline in the spread's predictive power by simulating our benchmark model on the smoothed shock estimates obtained for the second sub-sample. The results of this exercise are presented in Table 1.10. Conditional on the second sub-sample shock estimates, the resultant expectational coefficients are all statistically insignificant. As such, we also observe a significant fall in the adjusted R-squared values for all forecasting horizons under this counterfactual exercise. Our reduced-form evidence is therefore indicative of the impact that changes in shock composition have played on the time variation in the US term spread's predictive power.

1.7 Structural Correlation Decomposition

In light of the previous section, we aim here to provide a structural interpretation of these findings by use of a structural correlation decomposition. Specifically, we use our structural model to decompose the unconditional correlation between the term spread and future growth rates in output to each of the structural shocks.[22] Furthermore, the decomposition is conducted over the same two sub-samples as before so that we can assess how the contribution of each shock has changed between the two sub-samples.

Table 1.11 reports the results of the decompositions. The second column of the table reports the unconditional correlation between the term spread and various growth rates in real output and, as to be expected, the model returns relatively higher correlation coefficients for the earlier sub-sample. Over the earlier sub-sample, it is clear that the monetary policy shock,

[22]See Andrle (2012) for a detailed note on how to decompose the correlations of a linear state-space model into the individual contributions of each exogenous innovation.

η^r, accounts for the major share of correlation at a forecasting horizon of 2 quarters. To gain insight into this result, Figure 1.3 presents selected impulse response functions implied by a positive monetary policy shock. The exogenous increase in the policy rate causes the term spread to decrease on impact, the response of output, however, displays a hump-shaped response due to the real frictions in the model. The output response is key here since, as the output growth horizon is increased, the inertia impacts the respective responses in two ways. First, we see not only a smaller decrease on impact but, more importantly, the turning point of the growth response begins to precede that of the term spreads. This explains why the model attributes a smaller share of correlation to the monetary policy shock as the growth horizon is increased.

Moreover, it is interesting to note that in the second sub-sample the contribution of monetary policy shocks, both in absolute and relative terms, has significantly fallen. One potential explanation behind this result may be related to the lack of credibility of the Federal Reserve in its commitment to achieving low and stable inflation in our earlier sub-sample (Goodfriend, 1993). Appealing to the Fisher equation, long-term rates are a function of inflation expectations, such that a monetary easing, for example, will prompt agents to revise their inflation expectations upwards, which in turn contributes to the widening of the term spread. Indeed, the change in inflation expectations are amplified in the absence of a credible commitment to stabilise inflation and will therefore precipitate a more pronounced signal emanating from the term spread prior to the monetary-induced change in output. Under this interpretation, our findings may be seen as complimentary to those of Bordo and Haubrich (2004).

One other potential explanation behind the diminished contribution of monetary policy shocks in our later sub-sample is the finding of several analyses to report the declining impact of exogenous changes in monetary policy on output since the mid 1980s (Bernanke and Mihov, 1998; Barth and Ramey, 2001; Boivin and Giannoni, 2006; Boivin et al., 2010). In the instance that monetary policy shocks have a muted impact on future output growth, it follows that the predictive capacity of the term spread will diminish.

One final observation for this sub-sample is that the risk-premium shock[23], η^b, accounts for a major share of correlation at all growth horizons. From Figure 1.4, the risk premium shock encourages agents to bring forward consumption and investment causing inflationary pressures to build. Consequently, the endogenous response of the Central bank causes the term spread to sharply decrease on impact. It is clear from Figure 1.4 that the initial decrease in the term spread leads the negative realised growth rate in output at all horizons. Furthermore, contrast to the monetary policy shock, the turning point of all growth rate responses never precede that of the term spreads due to the limited inertia in the output response. This explains why the model attaches a large share of the correlation to the risk premium shock at all horizons.

Similar to the monetary policy shock, the contribution of the risk-premium shock is found to have fallen in both absolute and relative terms in our second sub-sample. As discussed by Fisher (2015), the risk-premium shock in our analysis may be interpreted as a shock to the demand for safe and liquid assets such as short-term debt issued by the US treasury. This interpretation is particularly interesting in light of the policies geared towards deregulating US financial markets in the 1980s. In particular, prior to the early 1980s, Regulation Q imposed interest rate ceilings on savings and time deposits held at commercial banks. Indeed, Gilbert (1986) and Mertens (2008) show that throughout our earlier sub-sample of the 1960s and 1970s, these interest rate ceilings were often binding[24] and contributed to the large withdrawals in said deposits from commercial banks observed over this period. Moreover, Cook (1981) provides evidence that savers, in order to take advantage of higher market yields, increased their demand for liquid short-term Treasury Bills by diverting their deposits into money market funds[25]. By driving a wedge between the market rate and the rate offered on household deposits, it is plausible that Regulation Q may be key to explaining why the

[23]As discussed in Smets and Wouters (2007), this shock introduces a wedge between the policy rate and the return on assets held by the household.

[24]That is, the interest rate ceilings were lower than the return offered on market instruments.

[25]See Cook and Duffield (1979) for a discussion on the growth of money market funds in the late 1970s that were established in order to placate the growing demand from savers to access market rates of return.

risk-premium shock is estimated to be an important contributor to the correlation between the spread and future output growth in our earlier sub-sample. Moreover, financial market liberalisation and the subsequent repeal of Regulation Q in the 1980s, is also consistent with the finding that the risk-premium shock has diminished in importance in our later second sub-sample[26].

In the case of the later sub-sample, it is clear that the relative importance of shocks driving the correlation between the term spread and future output growth has shifted significantly. In this part of our sample we observe that the investment shock, η^i dominates in accounting for the correlation at all horizons over this sub-sample[27]. Indeed, this result is complimentary to several other studies that report the significance of the investment shock in explaining US business-cycle fluctuations (Greenwood et al., 1997, 2000; Fisher, 2006; Justiniano and Primiceri, 2008; Justiniano et al., 2010). In particular, Justiniano and Primiceri (2008) provide evidence that changes in the volatility of the investment shock are key to understanding the significant fall in the volatilities of key macroeconomic aggregates in the US since the late 1980s - the so called "Great Moderation" period. The investment shock exposited in these class of models impacts the efficiency in which the final good is transformed into productive capital. As these authours argue, if firms rely on external financing to purchase investment goods, then it follows that the cost of external finance in addition to the efficiency in which the financial sector intermediates credit, should be reflected through the variation in the investment shock. Consistent with this view, Justiniano and Primiceri (2008) and Justiniano et al. (2011) discuss how the liberalisation of US financial markets over this period has indeed widened access to credit for households and firms. The importance our model attributes to the investment shock over this period may therefore be picking up the impact of financial

[26]This is not only reflected in terms of its contribution to the spread-output growth correlation, but also concerning the estimates of the parameters governing the process of this exogenous shock i.e. its persistence and variance (see Table 5).

[27]Furthermore, the contribution of the investment shock increases significantly as the growth horizon is increased.

market deregulation on the allocation of credit to borrowers[28].

We now ask - why did a shift of relative importance in favour of the investment shock contribute to the decline in the term spread's predictive power? From Figure 1.5, a positive investment shock boosts the capital stock thereby causing output to increase in a persistent and inertial manner[29]. Similarly, we observe a positively hump-shaped response for inflation prompting the Central bank to gradually tighten policy, hence the inertia also observed in the term spread response. It is striking to note that in spite of the term spread decreasing on impact, realised output growth at all horizons is initially positive. Clearly, such responses are inconsistent with a term spread that leads output growth and therefore supports our reduced-form evidence in finding that changes to the relative importance of exogenous disturbances is an important factor in accounting for the decline in the spread's predictive power.

1.8 Conclusion

This paper has provided a structural interpretation of the recent decline in the US term spread's forecasting capacity. In so doing, we have contributed to the theoretical debate on why the term spread leads output growth. We first discounted the conjecture that time-varying term premia may have been a factor in weakening the reliability of the spread as a leading indicator. This was made apparent after a decomposition of the term spread revealed the risk-adjusted term spread to be statistically insignificant when regressed on future output. Through the use of counterfactual analysis we found that a shift in the relative importance of shocks driving US term spread fluctuations to be the most likely explanation in accounting for the decline in its predictive power. Indeed, a structural correlation decomposition revealed that for the second sub-sample, the unconditional correlation between the spread and future

[28] Indeed, Bernanke et al. (1999) contend that the implication of models, such as ours, that do not explicitly model financial frictions in the form of agency costs a la Carlstrom and Fuerst (1997), is that such financial effects will instead be captured by variation in the investment shock.

[29] See for a discussion on how the investment shock is propagated in these class of models Justiniano et al. (2010).

output growth is predominately driven by shocks to the marginal efficiency of investment. Inspection of the respective impulse response functions, however, reveal that an investment shock leads to an impact response that is inconsistent with the term spread positively leading future realised output growth.

1.9 Tables

Table 1.1: Regression Analysis (I)

		Equation (1.1)		
Sample Period	k	α_0	α_1	$\bar{R}^2$
1966:1 - 2006:4				
	2	1.83***	0.87***	0.17
		(4.04)	(4.14)	
	4	1.95***	0.82***	0.23
		(4.40)	(4.05)	
	6	2.14***	0.71***	0.23
		(5.14)	(3.93)	
	8	2.38***	0.57***	0.19
		(6.52)	(3.85)	
1966:1 - 1979:2				
	2	1.69**	1.67***	0.32
		(2.41)	(4.10)	
	4	2.00***	1.50***	0.41
		(2.86)	(3.90)	
	6	2.40***	1.19***	0.33
		(3.66)	(3.74)	
	8	2.76***	0.86***	0.23
		(5.18)	(3.56)	
1984:1 - 2006:4				
	2	2.57***	0.35	0.04
		(4.27)	(1.53)	
	4	2.63***	0.35	0.05
		(4.00)	(1.41)	
	6	2.50***	0.43*	0.10
		(3.97)	(1.76)	
	8	2.60***	0.38*	0.10
		(4.56)	(1.78)	

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Models:

Equation (1.1): $(400/k)\left(\ln Y_{t+k}^D - \ln Y_t^D\right) = \alpha_0 + \alpha_1 SP_t^D + \varepsilon_t$

Table 1.2: Regression Analysis (II)

		Equation (1.1)			Equation (1.2)			
Sample Period	k	α_0	α_1	$\bar{R}^2$	β_0	β_1	β_2	$\bar{R}^2$
1966:1 - 2006:4								
	2	1.83***	0.87***	0.17	3.61***	0.61**	−0.21**	0.22
		(4.04)	(4.14)		(3.86)	(2.45)	(-1.98)	
	4	1.95***	0.82***	0.23	3.37***	0.61**	−0.17*	0.28
		(4.40)	(4.05)		(3.80)	(2.56)	(-1.84)	
	6	2.14***	0.71***	0.23	3.25***	0.54**	−0.13	0.27
		(5.14)	(3.93)		(3.69)	(2.41)	(-1.53)	
	8	2.38***	0.57***	0.19	3.21***	0.44**	−0.10	0.22
		(6.52)	(3.85)		(3.86)	(2.26)	(-1.19)	
1966:1 - 1979:2								
	2	1.69**	1.67***	0.32	8.11***	0.68*	−0.86***	0.52
		(2.41)	(4.10)		(5.79)	(1.87)	(-4.86)	
	4	2.00***	1.50***	0.41	7.14***	0.74**	−0.71***	0.65
		(2.86)	(3.90)		(5.23)	(2.39)	(-4.12)	
	6	2.40***	1.19***	0.33	6.30***	0.60**	−0.55**	0.53
		(3.66)	(3.74)		(4.25)	(2.18)	(-2.63)	
	8	2.76***	0.86***	0.23	5.51***	0.44	−0.40**	0.37
		(5.18)	(3.56)		(4.40)	(1.63)	(-2.31)	
1984:1 - 2006:4								
	2	2.57***	0.35	0.04	2.09**	0.40*	0.07	0.04
		(4.27)	(1.53)		(2.47)	(1.70)	(0.48)	
	4	2.63***	0.35	0.05	2.05**	0.41	0.09	0.06
		(4.00)	(1.41)		(2.36)	(1.58)	(0.40)	
	6	2.50***	0.43*	0.10	1.81**	0.49*	0.10	0.13
		(3.97)	(1.76)		(2.10)	(1.89)	(1.11)	
	8	2.60***	0.38*	0.10	1.81**	0.45*	0.11	0.15
		(4.56)	(1.78)		(2.29)	(1.96)	(1.47)	

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Models:

$$\text{Equation (1.1):}\ \ (400/k)\left(\ln Y_{t+k}^{D} - \ln Y_{t}^{D}\right) = \alpha_0 + \alpha_1 SP_t^D + \varepsilon_t$$

$$\text{Equation (1.2):}\ \ (400/k)\left(\ln Y_{t+k}^{D} - \ln Y_{t}^{D}\right) = \beta_0 + \beta_1 SP_t^D + \beta_2 FFR_t^D + \upsilon_t$$

Table 1.3: Linearised Equilibrium Conditions of the Smets and Wouters (2007) Model

(1)	$c_t = \frac{\frac{h}{\gamma}}{1+\frac{\iota_c}{\gamma}} c_{t-1} + \frac{1}{1+\frac{\iota_c}{\gamma}} E_t c_{t+1} + \frac{\left(1-\frac{\iota_c}{\gamma}\right)(\sigma_c - 1) l_*^{1+\sigma_l}}{1+\frac{\iota_c}{\gamma}} \left(l_t - E_t l_{t+1}\right) - \frac{1-\frac{\iota_c}{\gamma}}{\sigma_c\left(1+\frac{\iota_c}{\gamma}\right)} E_t \left[r_{t,t+1} - \pi_{t,t+1}\right] + \eta_t^b$
(2)	$i_t = \frac{1}{\varphi\gamma^2\left(1+\bar{\beta}\gamma\right)} q_t + \frac{1}{1+\bar{\beta}\gamma} i_{t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t i_{t+1} + \eta_t^i$
(3)	$q_t = \bar{\beta} r_*^k E_t r_{t,t+1}^k + \bar{\beta}(1-\delta) E_t q_{t+1} - \left(r_{t,t+1} - E_t \pi_{t,t+1} + \eta_t^b\right)$
(4)	$r_{t-1,t}^k = \frac{\psi}{1-\psi} z_t$
(5)	$k_t = \frac{(1-\delta)}{\gamma} k_{t-1} + \frac{i_*}{k_*} \left(\tilde{I}_t + \gamma^2 \varphi \tilde{\eta}_t^i\right)$
(6)	$\bar{k}_t = z_t + k_{t-1}$
(7)	$w_t = \frac{(1-\bar{\beta}\xi_w\gamma)(1-\xi_w)}{\xi_w\left(1+\bar{\beta}\gamma\right)} \frac{1}{(\phi_w - 1)\epsilon_w + 1} \left(\frac{1}{1-\frac{\iota_c}{\gamma}} c_t - \frac{\frac{\iota_c}{\gamma}}{1-\frac{\iota_c}{\gamma}} c_{t-1} + \sigma_l l_t - w_t\right) + \frac{\iota_w}{1+\bar{\beta}\gamma} \pi_{t-2,t-1} - \frac{1+\bar{\beta}\iota_w\xi_w\gamma}{1+\bar{\beta}\gamma} \pi_{t-1,t}$ $+ \frac{1}{1+\bar{\beta}\gamma} w_{t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t w_{t+1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t \pi_{t,t+1} + \eta_t^w$
(8)	$y_t = \phi\left(\eta_t^a + \alpha \bar{k}_t + (1-\alpha) l_t\right)$
(9)	$mc_t = (1-\alpha) w_t + \alpha r_{t-1,t}^k - \eta_t^a$
(10)	$\bar{k}_t = w_t - r_{t-1,t}^k + l_t$
(11)	$\pi_{t-1,t} = \frac{\left(1-\bar{\beta}\xi_p\gamma\right)(1-\xi_p)}{\xi_p\left(1+\bar{\beta}\iota_p\gamma\right)} \frac{1}{(\phi_p - 1)\epsilon_p + 1} mc_t + \frac{\iota_p}{1+\bar{\beta}\iota_p\gamma} \pi_{t-2,t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\iota_p\gamma} E_t \pi_{t,t+1} + \eta_t^p$
(12)	$y_t = \frac{c_*}{y_*} c_t + \frac{i_*}{y_*} i_t + r_*^k \frac{k_*}{y_*\gamma} z_t + \eta_t^g$
(13)	$r_{t,t+1} = \rho r_{t-1,t} + (1-\rho)\left(r_\pi \pi_{t-1,t} + r_y\left(y_t - y_t^f\right)\right) + r_{\Delta y}\left(y_t - y_{t-1} - y_t^f + y_{t-1}^f\right) + \eta_t^r$
(14)	$\eta_t^b = \rho_b \eta_{t-1}^b + \epsilon_t^b$
(15)	$\eta_t^i = \rho_i \eta_{t-1}^i + \epsilon_t^i$
(16)	$\eta_t^w = \rho_w \eta_{t-1}^w + \epsilon_t^w - \mu_w \epsilon_{t-1}^w$
(17)	$\eta_t^a = \rho_a \eta_{t-1}^a + \epsilon_t^a$
(18)	$\eta_t^p = \rho_p \eta_{t-1}^p + \epsilon_t^p - \mu_p \epsilon_{t-1}^p$
(19)	$\eta_t^g = \rho_g \eta_{t-1}^g + \epsilon_t^g + \rho_{ag} \epsilon_t^a$
(20)	$\eta_t^r = \rho_r \eta_{t-1}^r + \epsilon_t^r$

Notes: a. Endogenous variables include: c, consumption, l, labour, r, nominal interest rate, π, inflation, i, investment, q price of installed capital, r^k, return on capital, z_t, capacity utilisation rate, k, physical capital, $\bar{k}$, effective capital, w, real wage rate, y, output, m, real marginal costs.
b. Exogenous shocks include: η^b, wedge shock, η^i, marginal efficiency of investment shock, η^w, wage mark-up shock, η^a, tfp shock, η^p, price mark-up shock, η^g, exogenous spending shock, η^r, interest rate shock.
c. As in Smets and Wouters (2007) the flexible-price economy is the economy pertaining to the absence of mark-up shocks and flexible wages and prices. We denote the flexible-price counterpart of endogenous variables via the superscript "f".

Table 1.4: Full Sample Estimates: 1966Q1 - 2006Q4

		Prior			Posterior		
Parameter	Description	Density	Mean	Std.dev.	Mean	10^{th}	90^{th}
φ	Investment adjustment cost	N	4.00	1.50	5.89	4.26	7.58
σ_c	Inverse I.E.S	N	1.50	0.37	1.33	1.13	1.53
ι_c	Consumption habit	B	0.70	0.10	0.73	0.66	0.79
ξ_w	Calvo wage	B	0.50	0.10	0.75	0.65	0.85
σ_l	Elast. labour supply	N	2.00	0.75	2.08	1.08	3.01
ξ_p	Calvo prices	B	0.50	0.10	0.69	0.61	0.77
ι_w	Wage indexation	B	0.50	0.15	0.59	0.38	0.80
ι_p	Price indexation	B	0.50	0.15	0.30	0.13	0.45
ψ	Utilisation cost	B	0.50	0.15	0.55	0.38	0.73
ϕ	Fixed cost	N	1.25	0.12	1.64	1.51	1.77
r_π	Taylor rule inflation	N	1.50	0.25	1.97	1.67	2.26
ρ	Taylor rule smoothing	N	0.75	0.10	0.81	0.76	0.85
r_y	Taylor rule output	N	0.12	0.05	0.06	0.02	0.09
$r_{\Delta y}$	Taylor rule Δ output	N	0.12	0.05	0.22	0.18	0.27
$\bar{\pi}$	SS inflation	G	0.80	0.10	1.00	0.86	1.13
$100 \cdot \left(\beta^{-1} - 1\right)$	Discount factor	G	0.25	0.10	0.16	0.07	0.25
$\bar{l}$	SS hours	N	0.00	2.00	6.16	3.91	8.45
$\bar{\gamma}$	Trend growth	N	0.40	0.10	0.42	0.40	0.45
α	Capital share	N	0.30	0.05	0.20	0.17	0.22
$\mathfrak{c}$	SS term spread	N	0.25	0.10	0.25	0.12	0.38
κ	NKPC slope	-	-	-	0.01	-	-
σ_a	Std.Dev. TFP	IG	0.10	2.00	0.45	0.41	0.49
σ_b	Std.Dev. Risk premium	IG	0.10	2.00	0.24	0.20	0.28
σ_g	Std.Dev. Govt' spending	IG	0.10	2.00	0.52	0.47	0.56
σ_i	Std.Dev. Inv-specific	IG	0.10	2.00	0.42	0.35	0.49
σ_r	Std.Dev. Monetary policy	IG	0.10	2.00	0.24	0.21	0.26
σ_p	Std.Dev. Price mark-up	IG	0.10	2.00	0.14	0.12	0.16
σ_w	Std.Dev. Wage mark-up	IG	0.10	2.00	0.25	0.22	0.29
σ_m	Std. Measurement	U	2.00	2.00	0.71	0.65	0.78
ρ_a	AR(1) TFP	B	0.50	0.20	0.95	0.93	0.97
ρ_b	AR(1) Risk premium	B	0.50	0.20	0.23	0.08	0.36
ρ_g	AR(1) Govt.	B	0.50	0.20	0.97	0.96	0.99
ρ_i	AR(1) Inv-specific	B	0.50	0.20	0.73	0.64	0.82
ρ_r	AR(1) Mon. Pol	B	0.50	0.20	0.17	0.06	0.28
ρ_p	AR(1) P.M up	B	0.50	0.20	0.89	0.83	0.96
ρ_w	AR(1) W.M up	B	0.50	0.20	0.96	0.93	0.98
μ_p	MA(1) P.M up	B	0.50	0.20	0.75	0.62	0.88
μ_w	MA(1) W.M up	B	0.50	0.20	0.85	0.76	0.94
ρ_{ga}	AR(1) TFP/Govt.	B	0.50	0.20	0.54	0.40	0.68
δ	Depreciate rate	-	0.025	-	-	-	-
ϕ_w	SS Wage mark-up	-	1.50	-	-	-	-
g_y	Govt' spending/Output	-	0.18	-	-	-	-
ϵ_p	Kimball price	-	10.0	-	-	-	-
ϵ_w	Kimball wage	-	10.0	-	-	-	-

Notes: a. The posterior distributions are sampled by running two parallel chains of 250000 replications of the Metropolis Hastings algorithm. Convergence is checked by using the metrics provided by Brooks and Gelman (1998).

Table 1.5: Sub-Sample Estimates

Structural Parameters					Shock Processes				
	1964Q1 - 1979Q2		1982Q1 - 2006Q4			1964Q1 - 1979Q2		1982Q1 - 2006Q4	
	Mode	Std.Dev.	Mode	Std.Dev.		Mode	Std.Dev.	Mode	Std.Dev.
φ	4.67	1.06	6.71	1.14	σ_a	0.55	0.06	0.36	0.03
σ_c	1.23	0.13	1.56	0.13	σ_b	0.25	0.04	0.18	0.02
ι_c	0.70	0.06	0.66	0.05	σ_g	0.53	0.05	0.40	0.03
ξ_w	0.80	0.06	0.72	0.09	σ_i	0.43	0.09	0.35	0.05
σ_l	1.42	0.70	2.12	0.66	σ_r	0.23	0.02	0.11	0.01
ξ_p	0.53	0.06	0.74	0.05	σ_p	0.22	0.03	0.10	0.01
ι_w	0.59	0.12	0.48	0.17	σ_w	0.21	0.03	0.27	0.03
ι_p	0.46	0.20	0.26	0.13	ρ_a	0.91	0.05	0.93	0.02
ψ	0.31	0.14	0.69	0.11	ρ_b	0.33	0.15	0.21	0.11
ϕ	1.40	0.09	1.60	0.09	ρ_g	0.92	0.04	0.97	0.01
r_π	1.51	0.22	1.96	0.20	ρ_i	0.69	0.11	0.72	0.06
ι_r	0.86	0.04	0.84	0.02	ρ_r	0.36	0.11	0.31	0.08
r_y	0.09	0.04	0.05	0.03	ρ_p	0.69	0.23	0.83	0.08
$r_{\Delta y}$	0.23	0.03	0.14	0.02	ρ_w	0.95	0.02	0.87	0.06
$\bar{\pi}$	0.80	0.11	0.71	0.07	μ_p	0.55	0.21	0.68	0.13
$\beta^{-1} - 1$	0.24	0.09	0.13	0.05	μ_w	0.92	0.03	0.72	0.10
$\bar{l}$	2.82	1.69	8.51	1.05	ρ_{ga}	0.60	0.11	0.41	0.10
$\bar{\gamma}$	0.39	0.04	0.44	0.02	σ_m	0.42	0.04	0.59	0.04
α	0.20	0.03	0.21	0.02	$\mathfrak{c}$	0.29	0.08	0.31	0.08
κ	0.06	-	0.01	-					

Table 1.6: Correlation Coefficients

	Measurement Error	Kim-Wright	VAR	Cochrane-Piazzesi	λ_1
Kim-Wright	0.84 [0.92]	1.00			
VAR	0.83 [0.98]	0.91	1.00		
Cochrane-Piazzesi	0.74 [0.84]	0.97	0.86	1.00	
λ_1	0.83 [0.93]	0.99	0.95	0.97	1.00

Notes: a. Values in square parantheses reported in the first column correspond to correlation coefficients computed over the smaller sample of 1982Q1 - 2006Q4.

Table 1.7: Regression Analysis (III)

		Equation (1.1)			Equation (1.8)				
Sample Period	k	α_0	α_1	$\bar{R}^2$	γ_0	γ_1	γ_2	Test: χ^2 $H_0: \gamma_1 = \gamma_2$	$\bar{R}^2$
1966:1 - 1979:2									
	2	1.69**	1.67***	0.32	3.69***	1.56***	0.68*	23.6***	0.52
		(2.41)	(4.10)		(12.1)	(6.03)	(1.87)		
	4	2.00***	1.50***	0.41	3.66***	1.47***	0.74**	16.9***	0.65
		(2.86)	(3.90)		(14.0)	(7.24)	(2.39)		
	6	2.40***	1.19***	0.33	3.62***	1.17***	0.60**	6.91***	0.53
		(3.66)	(3.74)		(11.9)	(5.59)	(2.18)		
	8	2.76***	0.86***	0.23	3.63***	0.84***	0.48*	4.93**	0.33
		(5.18)	(3.56)		(10.3)	(4.15)	(1.80)		
1984:1 - 2006:4									
	2	2.57***	0.35	0.04	3.03***	0.33	0.40*	0.50	0.04
		(4.27)	(1.53)		(8.02)	(1.39)	(1.70)		
	4	2.63***	0.35	0.05	3.08***	0.32	0.41	0.72	0.06
		(4.00)	(1.41)		(7.69)	(1.24)	(1.58)		
	6	2.50***	0.43*	0.10	3.03***	0.38	0.49*	1.22	0.13
		(3.97)	(1.76)		(7.81)	(1.53)	(1.89)		
	8	2.60***	0.38*	0.10	3.05***	0.34	0.44*	1.50	0.14
		(4.56)	(1.78)		(8.71)	(1.56)	(1.93)		

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Figures for the Wald test in column 9 denote χ^2 test statistics.*, **, and *** denote rejection of the null hypothesis that the coefficient of the expectational component equals that of the term premium at the 10%, 5% and 1% level respectively.
d. Models:

$$\text{Equation (1.1)}: (400/k)\left(\ln Y_{t+k}^D - \ln Y_t^D\right) = \alpha_0 + \alpha_1 SP_t^D + \varepsilon_t$$

$$\text{Equation (1.8)}: (400/k)\left(\ln Y_{t+k}^D - \ln Y_t^D\right) = \gamma_0 + \gamma_1 \left(\frac{1}{40}\sum_{k=0}^{39} E_t\left\{r_{t+k,(1)}^M\right\} - r_{t,(1)}^M\right) + \gamma_2 \eta_t^m + \upsilon_t$$

Table 1.8: Regression Analysis (IV)

		Benchmark			CF (I)		
Sample Period	k	α_0	α_1	$\bar{R}^2$	$\alpha_{0,1}$	$\alpha_{1,1}$	
1966:1 - 1979:2							
	2	3.64***	1.10***	0.50	2.58***	1.18***	0.49
		(10.5)	(8.89)		(7.56)	(11.4)	
	4	3.56***	0.95***	0.58	2.74***	0.95***	0.49
		(11.1)	(7.32)		(6.10)	(5.26)	
	6	3.49***	0.74***	0.48	2.95***	0.68***	0.34
		(9.80)	(4.10)		(5.87)	(3.15)	
	8	3.51***	0.49***	0.29	3.22***	0.40***	0.15
		(9.34)	(3.83)		(7.39)	(2.69)	

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Experiments: CF (I): we change only the values of the monetary reaction coefficients to the estimates obtained in the second sub-sample.

Table 1.9: Regression Analysis (V)

		Benchmark			CF (II)		
Sample Period	k	α_0	α_1	$\bar{R}^2$	$\alpha_{0,1}$	$\alpha_{1,1}$	
1966:1 - 1979:2							
	2	3.64***	1.10***	0.50	3.11***	1.17***	0.46
		(10.5)	(8.89)		(8.52)	(8.59)	
	4	3.56***	0.95***	0.58	3.12***	0.99***	0.52
		(11.1)	(7.32)		(8.27)	(6.51)	
	6	3.49***	0.74***	0.48	3.18***	0.74***	0.40
		(9.80)	(4.10)		(7.44)	(3.70)	
	8	3.51***	0.49***	0.29	3.32***	0.47***	0.21
		(9.34)	(3.83)		(8.05)	(3.26)	

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Experiments: CF (II) - we change only the values of the NKPC slope to the estimates obtained in the second sub-sample.

Table 1.10: Regression Analysis (VI)

Benchmark				CF (III)			
Sample: 1966:1 - 1979:2				Sample: 1982:1 - 2006:4			
k	α_0	α_1	$\bar{R}^2$	k	α_0	α_1	$\bar{R}^2$
2	3.64***	1.10***	0.50	2	3.29***	−0.03	0.00
	(10.5)	(8.89)			(8.76)	(-0.23)	
4	3.56***	0.95***	0.58	4	3.41***	−0.10	0.02
	(11.1)	(7.32)			(10.1)	(-0.70)	
6	3.49***	0.74***	0.48	6	3.43***	−0.12	0.05
	(9.80)	(4.10)			(11.8)	(-1.06)	
8	3.51***	0.49***	0.29	8	3.41***	−0.10	0.04
	(9.34)	(3.83)			(13.6)	(-1.06)	

Notes: a. In parantheses presented below the coefficient estimates we report the corresponding t-statistics. The standard errors used to compute the t-statistics have been adjusted via the methodology proposed by Newey and West (1987) to correct for autocorrelation and heteroskedasticity.
b. *, **, and *** denotes statistical significance at the 10%, 5% and 1% level respectively using a two-tailed test.
c. Experiments: CF (III) - we simulate our benchmark model on the second sub-sample smoothed shock estimates.

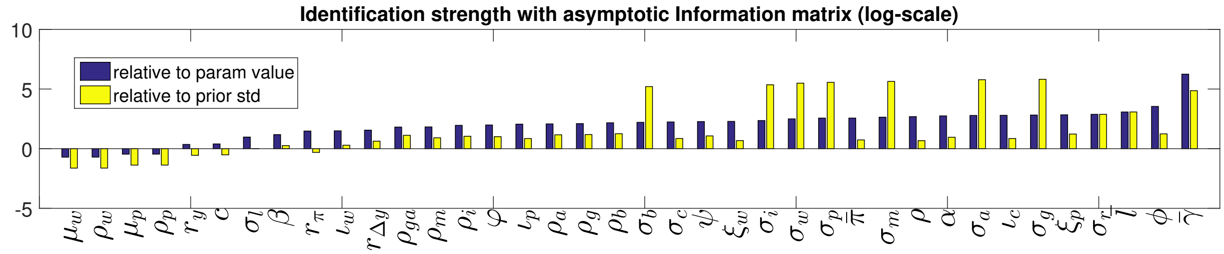
Table 1.11: Structural Correlation Decomposition

	1964:1 - 1979:2							
	Model	η^a	η^b	η^g	η^i	η^r	η^p	η^w
Term Spread								
k = 2	0.75	0.09	0.17	0.07	0.08	0.22	0.04	0.08
k = 4	0.70	0.04	0.19	0.07	0.12	0.16	0.04	0.08
k = 6	0.61	0.01	0.18	0.07	0.14	0.11	0.03	0.07
k = 8	0.51	-0.03	0.17	0.07	0.15	0.08	0.02	0.06
	1982:1 - 2006:6							
	Model	η^a	η^b	η^g	η^i	η^r	η^p	η^w
Term Spread								
k = 2	0.49	0.05	0.07	0.05	0.10	0.07	0.07	0.08
k = 4	0.50	0.03	0.07	0.05	0.18	0.03	0.06	0.08
k = 6	0.48	0.02	0.07	0.05	0.24	0.00	0.04	0.06
k = 8	0.44	0.00	0.07	0.06	0.29	-0.02	0.02	0.04

Notes: a. The second column of the table reports the unconditional correlation between the term spread and various growth rates of future GDP implied by our model. The columns thereafter report the contributions of each shock to the unconditional correlation, where η^a: TFP, η^b: risk premium, η^g: Government spending, η^i: investment, η^r: monetary policy, η^p: price mark-up, η^w: wage mark-up.

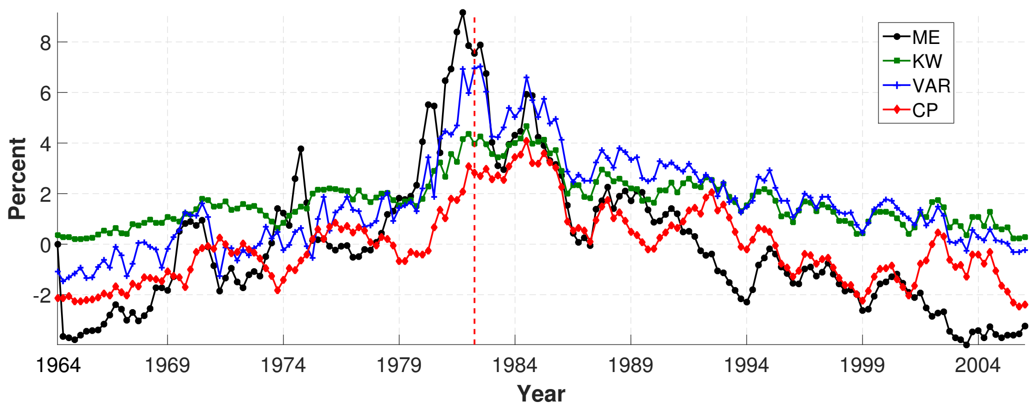
1.10 Figures

Figure 1.1: Parameter Identification



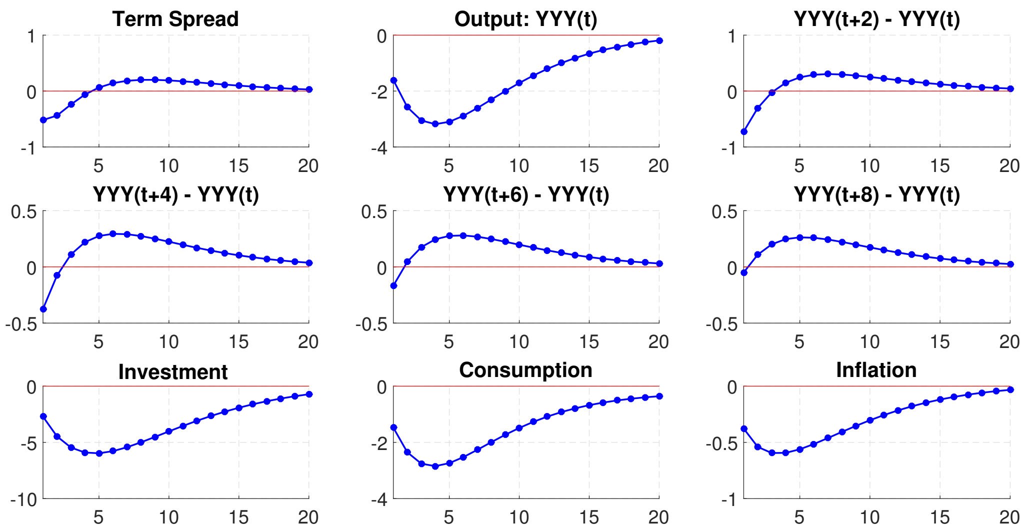
Notes: Using the routines developed by Ratto and Iskrev (2011) for DYNARE, the above figure plots the identification strength of parameters in increasing order from left to right. As discussed by Pfeifer (2014), parameters that are not identified imply that the likelihood function is flat in their corresponding direction. This would be reflected by an identification strength of 0 (blue bars) in the graph above.

Figure 1.2: Term Premia Estimates



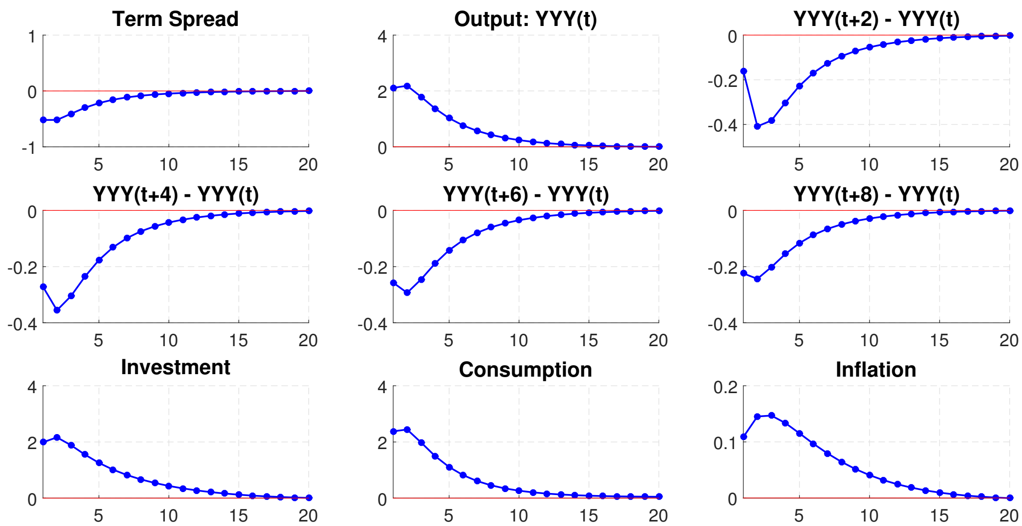
Notes: The figure plots the measurement error, our proxy for term premia, alongside other estimates of the 10 year term premium found in the literature. KW: Kim and Wright (2005) measure, VAR: measure based on a Vector Autoregression as in Evans and Marshall (2001), CP: Cochrane and Piazzesi (2005) measure.

Figure 1.3: Impulse Response Functions: $\eta_t^r \uparrow$



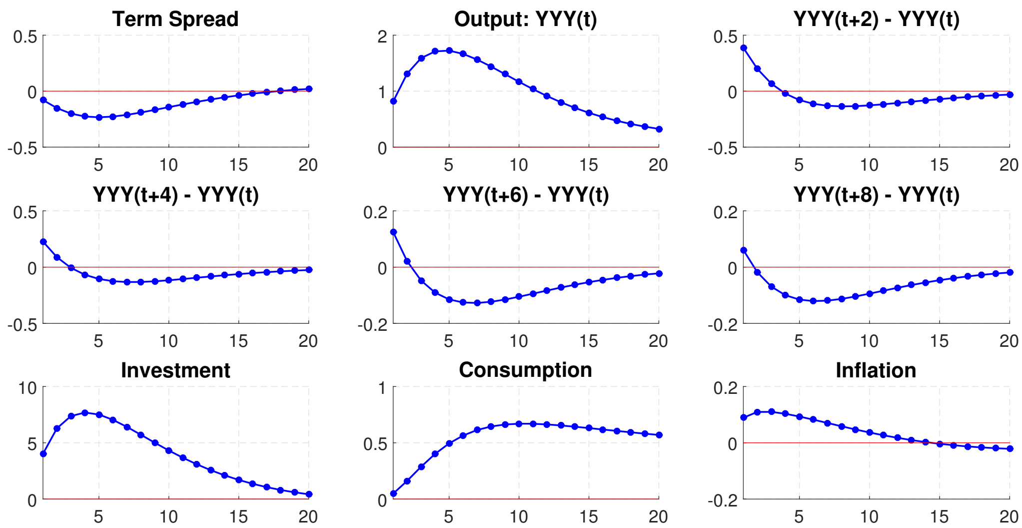
Notes: Presented are the impulse response functions to a positive monetary policy shock. The impulse responses are computed using the mode of the posterior distribution computed over the 1966:1 - 1979:2 sub-sample. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 1.4: Impulse Response Functions: $\eta_t^b \uparrow$



Notes: Impulse response functions to a positive risk premium shock. The impulse responses are computed using the mode of the posterior distribution computed over the 1966:1 - 1979:2 sub-sample. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 1.5: Impulse Response Functions: $\eta_t^i \uparrow$



Notes: Impulse response functions to a positive investment shock. The impulse responses are computed using the mode of the posterior distribution computed over the 1984:1 - 2006:4 sub-sample. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

1.11 Appendices

1.A Data

Definition of observable variables used in the estimation:

- Output $= \ln(\text{GDPC1}/\text{LNSindex}) * 100$
- Consumption $= \ln((\text{PCEC}/\text{GDPDEF})/\text{LNSindex}) * 100$
- Investment $= \ln((\text{FPI}/\text{GDPDEF})/\text{LNSindex}) * 100$
- Hours $= \ln((\text{PRS85006023} * \text{CE16OV}/100)/\text{LNSindex}) * 100$
- Real Wage $= \ln(\text{PRS85006103}/\text{GDPDEF}) * 100$
- Inflation $= \ln(\text{GDPDEF}/\text{GDPDEF}(-1)) * 100$
- Interest Rate = FEDFUNDS / 4
- Term Spread = (DGS10 - TB3MS) / 4

Source of original data:

- GDPC1: Real Gross Domestic Product - Billions of Chained 2009 Dollars, Seasonally Adjusted Annual Rate.
  Source: U.S. Department of Commerce, Bureau of Economic Analysis.
- LNS11000000: Civilian Labor Force Status : Civilian no-institutional population - Age: 16 years and over -Seasonally Adjusted - Number in thousands.
  Source: U.S. Bureau of Labor Statistics.
- LNSindex: LNS10000000(1992:3) = 1.

- PCEC: Personal Consumption Expenditures - Billions of Dollars, Seasonally Adjusted Annual Rate.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- GDPDEF: Gross Domestic Product - Implicit Price Deflator - 2009=100, Seasonally Adjusted.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- FPI: Fixed Private Investment - Billions of Dollars, Seasonally Adjusted Annual Rate.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- PRS85006103: Non-farm Business, All Persons, Hourly Compensation Duration: index, 2009 =100, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- CE16OV: Civilian Employment: Sixteen Years & Over, Thousands, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- CE16OV index: CE16OV (1992:3)=1

- PRS85006103: Non-farm Business, All Persons, Hourly Compensation Duration: index, 2009 =100, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- FEDFUNDS: Averages of Daily Figures - Percent.

  Source: Board of Governors of the Federal Reserve System (Before 1954: 3-Month Treasury Bill Rate, Secondary Market Averages of Business Days, Discount Basis)

- DGS10: 10 Year Treasury Constant Maturity Rate, Not Seasonally Adjusted, Percent.

  Source: Board of Governors of the Federal Reserve System.

- TB3MS: 3 Month Treasury Constant Maturity Rate, Not Seasonally Adjusted, Percent.
  Source: Board of Governors of the Federal Reserve System.

Chapter 2

Expectational Shocks and the US Term Spread

2.1 Introduction

This paper quantifies the extent to which shifts in the expectations of agents in the form of "news shocks" matter for explaining the variation in the slope of the term structure of interest rates. Our analysis is conducted within the framework of a medium-scale dynamic stochastic general equilibrium (DSGE) model.

The diversity of analyses into the term structure is indicative of the importance it plays, in particular, to the study of macroeconomics, finance and the interactions that connect these two disciplines. Empirical macroeconomic research, for example, has documented that developments in the US term spread[1] typically lead developments in real GDP growth (Laurent et al., 1989; Chen, 1991; Estrella and Hardouvelis, 1991). As discussed by Rudebusch et al. (2006), the theoretical basis for the term spread's predictive capacity can be motivated by regarding the long rate as a proxy for the neutral rate of interest i.e. that level of interest rate consistent with a closed output gap. Therefore, it follows that a change in the policy

[1]Defined as the difference between a long and short nominal Government spot rate.

rate relative to the neutral rate should be indicative of the position of monetary policy so that a steep term structure, for example, should imply accommodative policy and lead to subsequent economic growth. Graphically, the leading properties of the term spread can be observed in Figure 2.1. After lagging real output growth by 4 quarters, the two series appear to be positively correlated[2] thus supporting the idea that the term structure exhibits predictive properties. Despite long-standing recognition of the term spread as a leading pro-cyclical variable, the nature of the underlying innovations responsible for term-spread fluctuations has, until recently, eluded the literature. Filling this void, a recent paper by Kurmann and Otrok (2013*a*) has identified news about future total factor productivity (TFP) as a fundamental driver of term spread fluctuations. In response to a positive TFP news shock, the authours document contemporaneous falls in both inflation and the federal funds rate. Crucially, the loosening in the policy rate attenuates up the term structure, implying an increase in the term spread on impact. The response of output, however, exhibits no immediate response but then gradually begins to expand and track the anticipated increase in TFP thus confirming the term-spread as a leading pro-cyclical variable.

The findings of Kurmann and Otrok (2013*a*) compliment the growing interest in anticipated shocks that has been re-initiated due to the influential work of Beaudry and Portier (2006). In their paper, the authours use a bivariate structural VAR containing stock prices and TFP to identify their anticipated TFP shock. Their identification scheme is based on the premise that developments in the growth rate of future TFP are, to a great extent, anticipated and therefore priced into variables such as asset prices which are inherently forward looking. Furthermore, by expanding their system to include a variety of macro aggregates, the authours find that their anticipated shock explains a considerable fraction of the variation in consumption, hours and investment at business cycle frequencies thus providing empirical support for the earlier conjectures of Pigou (1929)[3].

[2]To the tune of 0.41.

[3]The interested reader is directed to Beaudry and Portier (2014) who provide a comprehensive survey of VAR-based empirical work on news shocks.

Following the work of Beaudry and Portier (2006) many authours have investigated the importance of news shocks within the framework of a dynamic general equilibrium model. One particular strand of research has examined the necessary frictions required to manufacture an expectation-led boom within a DSGE model[4] (Beaudry and Portier, 2004; Jaimovich and Rebelo, 2009; Den Haan and Kaltenbrunner, 2009; Kobayashi et al., 2010). Research has also been active in the use of estimated DSGE models to conduct structural decompositions of the source of fluctuations that are attributable to anticipated shocks. An important example is that of Schmitt-Grohé and Uribe (2012) who estimate a real business cycle model containing both anticipated and unanticipated components in the exogenous sources of uncertainty. The authours find that the anticipated sources of uncertainty account for half of the variation in output, consumption, investment and hours. Related, is the analysis of Khan and Tsoukalas (2012) who examine the importance of anticipated shocks within a medium-scale New Keynesian model. In contrast to Schmitt-Grohé and Uribe (2012), the authours find that it is the unanticipated shocks that account for the bulk of variation in consumption, investment, wages and the interest rate[5]. The variance of hours and inflation, however, are predominantly explained by the anticipated component of the wage mark-up shock suggesting that news unrelated to technological developments may play an important role in business cycle fluctuations. By comparison, less is known about the relative importance of news shocks in explaining the variation of asset prices within the context of a DSGE model. This is despite asset prices being a natural candidate to reflect expectational shocks since they are both forward looking and sufficiently flexible to accommodate the arrival of relevant news. A notable exception is the analysis of Guo (2011) who finds that expectational shocks pertaining to the future state of TFP to be significant a driver of the external

[4]This literature follows from the work of Barro and King (1984) who show that a standard one-sector real business cycle model is unable to generate an expectation led boom (positive co-movement in output, consumption, investment and hours) in receipt of favourable news regarding future productivity. See Krusell and McKay (2010) for a survey.

[5]The authours attribute the difference in results to the inclusion of nominal rigidities. Their reasoning is that endogenous price and wage mark-ups change the transmission mechanisms of their model in favour of the unanticipated shocks, particularly the shock to the marginal efficiency of investment.

finance premium. However, it remains to be seen whether their results remain robust in a more quantitatively relevant model featuring more rigidities and structural shocks.

Motivated by the findings of Kurmann and Otrok (2013*a*), we first quantitatively examine the role of a TFP news shock in explaining term spread fluctuations. To this end, we estimate a variant of the Smets and Wouters (2007) model and perform a structural decomposition of the term spread using US macro and interest rate data. Variance decompositions reveal that the monetary policy shock explains over 40% of term spread variation over our sample. Our model predicts that an exogenous tightening (loosening) of the policy rate engenders a flattening (steepening) of the yield curve which is then proceeded by an economic contraction (expansion). Therefore, conditional on a monetary policy shock, the term spread reflects the data in that is a leading and pro-cyclical variable, we offer this as a structural interpretation of why the model attributes a large share of term spread variation to the monetary policy shock. A key finding of our analysis is that our model attributes a negligible role to the TFP news shock in explaining term spread fluctuations, accounting for only 0.15% of its variance. Moreover, our results are consistent with those of Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012) in that they are indicative of the unimportance of stationary TFP news shocks in general, accounting for less than 5% of the variation in key macro aggregates. We then extend our analysis by considering other forms of news by accommodating an anticipated component in each exogenous process. However, our results find only a limited role for other forms of news, we find that it is the unanticipated disturbances which account for the majority of fluctuations in our model. In particular, unanticipated shocks jointly account for over 86% of the term spread's variance.

The rest of this paper is organised as follows. Section 2.2 provides details on the model economy and outlines the optimisation problems faced by its agents. Section 2.3 provides details on the estimation procedure. Sections 2.4 and 2.5 contain and discusses the main results of the paper. Section 2.6 concludes and offers potential avenues for future research.

2.2 The Model Economy

The benchmark model used in our paper is a close variant of the Smets and Wouters (2007) model. Minor differences include the use of the Dixit-Stiglitz aggregator as opposed to the aggregator proposed by Kimball (1995). Furthermore, we also exclude fixed costs in the production process. Our novelty stems from the use of the term spread in the measurement equation and the inclusion of anticipated components in the processes of the structural shocks.

The economy is defined by five types of agent: households, a labour packer, intermediate-good producing firms, final-good producing firms and a Government[6].

2.2.1 Households

A representative household, indexed over $i \in [0, 1]$, is assumed to maximise a utility function which is non-separable in consumption, $C_t(i)$ and labour supply, $H_t(i)$. Formally:

$$\max_{C_t(i),H_t(i)} E_t \sum_{k=0}^{\infty} \beta^k \left\{ \frac{\left(C_{t+k}(i) - \iota_c C_{t+k-1}\right)^{1-\sigma_c}}{1-\sigma_c} \exp\left\{ \frac{\sigma_c - 1}{1+\sigma_h} H_{t+k}(i)^{1+\sigma_h} \right\} \right\} \tag{2.1}$$

where β denotes the household's discount factor, ι_c controls the strength of the external consumption habit, σ_c is the inverse of the inter-temporal elasticity of substitution and σ_h denotes the elasticity of labour supply. The maximisation of (2.1) is subject to the household budget constraint which is presented below.

$$C_t(i) + I_t(i) + \frac{B^N_{1,t}(i)}{\zeta^b_t R_{t,t+1} P_t} + \sum_{j=2}^{40} \frac{\mathfrak{P}^N_{j,t}(i) B^N_{j,t}(i)}{P_t}$$

$$= W_t(i)H_t(i) + \left(U_t(i)R^K_{t-1,t} - F(U_t(i))\right)\bar{K}_{t-1}(i) + \frac{B_{1,t-1}(i)^N}{P_t} + \sum_{j=2}^{40} \frac{\mathfrak{P}^N_{j-1,t} B^N_{j,t-1}(i)}{P_t} + D_t - T_t \tag{2.2}$$

[6]Details on the model's equilibrium conditions can be found in the accompanying appendix.

Whereby households invest in a portfolio of nominal Government bonds where $\mathfrak{P}^N_{j,t}$ denotes today's price of a j-period bond and $B^N_{j,t}(i)$ denotes the quantity held. We assume that the one-period nominal bond, $B^N_{1,t}$, pays a risk-free gross return of $R_{t,t+1}$. Following Smets and Wouters (2007) we introduce a risk-premium shock denoted by ζ^b_t that drives a wedge between the interest rate set by the monetary authority and the return on the one-period bond. Furthermore, bonds of maturity $j > 1$ in our model have no implications for resource allocation and are assumed to be held in zero net supply. Investment is given by $I_t(i)$, $W_t(i)$ is the real wage, $R^K_{t-1,t}$ is the rental rate on effective capital, $K_t(i)$. D_t and T_t are representative of transfers from the intermediate firm and Government respectively. Before households are able to earn income from renting effective capital to firms, they must first transform it from physical capital via:

$$K_t(i) = U_t(i)\bar{K}_{t-1}(i) \tag{2.3}$$

where $U_t(i)$ denotes the intensity to which physical capital is transformed into effective capital. The cost, in terms of resources, of altering the intensity of capital use is given by the cost function $F\left(U_t(i)\right)$[7]. The capital stock is assumed to evolve according to:

$$\bar{K}_t(i) = (1-\delta)\bar{K}_{t-1}(i) + \zeta^i_t \left(1 - \Phi\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\right) I_t(i) \tag{2.4}$$

where δ is the fixed rate of depreciation and Φ represents a convex investment adjustment cost function that follows the formulation presented in Christiano et al. (2005)[8]. The shock ζ^i_t can be interpreted as a shock to the marginal efficiency of investment.

[7] $F = 0$, F' and $F'' > 0$

[8] $\Phi = \Phi' = 0$ and $\Phi'' > 0$.

2.2.2 Wage Setting

To introduce nominal rigidities into the wage setting process we follow the formulation presented in Erceg et al. (2000) and assume that individual labour supply, $H_t(i)$, is aggregated by a labour packer to form an index of labour input to be used in the production of the consumption good. The index of labour input is aggregated according to:

$$H_t = \left(\int_0^1 H_t(i)^{\frac{1}{1+\zeta_t^w}} di \right)^{1+\zeta_t^w} \tag{2.5}$$

where ζ_t^w denotes the elasticity of substitution between labour services. To permit a role for shocks to the mark-up of wages over the marginal rate of substitution between consumption and leisure we assume an ARMA(1,1) process[9] for ζ_t^w:

$$\ln \zeta_t^w = (1 - \rho_w) \ln \zeta^w + \rho_w \ln \zeta_{t-1}^w + \eta_t^w - \Theta_w \eta_{t-1}^w \tag{2.6}$$

Furthermore, aggregate labour demand is represented by H_t. Maximisation of the labour packer's problem yields the familiar demand function:

$$H_t(i) = \left(\frac{W_t(i)}{W_t} \right)^{-\frac{1+\zeta_t^w}{\zeta_t^w}} H_t \tag{2.7}$$

Staggered wage setting is introduced following the formulation presented in Calvo (1983) so that each period each household faces a constant probability, $\theta_w \in [0, 1]$, of being unable to re-optimise their wage rate, $W_t(i)$. For those households unable to re-optimise we assume the following indexation rule:

$$W_{t+k}(i) = \prod_{n=1}^{k} \frac{\gamma \Pi^{1-\iota_w} \Pi_{t-1,t-1+n}^{\iota_w}}{\Pi_{t,t+n}} W_t(i) \tag{2.8}$$

[9] As discussed by Smets and Wouters (2007), the motivation for including an MA term is that it allows the model to better capture the high frequency component in wage fluctuations.

where gross inflation is given by $\Pi_{t-1,t} = \frac{P_t}{P_{t-1}}$, γ denotes the steady state level of trend growth in the economy and $\iota_w \in [0,1]$ controls the strength of indexation. Furthermore, Π denotes the steady state inflation rate. The remaining fraction of households able to re-optimise their wage, $W_t(i)$, do so by solving the following optimisation problem subject to the demand constraint (2.7):

$$\max_{W_t(i)} E_t \sum_{k=0}^{\infty} \left\{ (\theta_w)^k \Lambda_{t,t+k}(i) \left(\begin{array}{c} \frac{(C_{t+k}(i)-\iota_c C_{t+k-1})^{1-\sigma_c}}{1-\sigma_c} \exp\left\{\frac{\sigma_c-1}{1+\sigma_h} H_{t+k}(i)^{1+\sigma_h}\right\} \\ +\lambda_{t+k}(i) \prod_{n=1}^{k} \frac{\gamma \Pi^{1-\iota_w} \Pi_{t-1,t-1+n}^{\iota_w}}{\Pi_{t,t+n}} W_t(i) H_{t+k}(i) \end{array} \right) \right\}$$

where $\Lambda_{t,t+k}(i)$ and $\lambda_{t+k}(i)$ is representative of the household stochastic discount factor and marginal utility of consumption respectively:

$$\Lambda_{t,t+1}(i) = \beta \frac{\lambda_{t+1}(i)}{\lambda_t(i)} = \beta \frac{(C_{t+1}(i) - \iota_c C_t)^{-\sigma_c} \exp\left\{\frac{\sigma_c-1}{1+\sigma_h} H_{t+1}(i)^{1+\sigma_h}\right\}}{(C_t(i) - \iota_c C_{t-1})^{-\sigma_c} \exp\left\{\frac{\sigma_c-1}{1+\sigma_h} H_t(i)^{1+\sigma_h}\right\}} \tag{2.9}$$

2.2.3 Final-Good Firms

For production, our economy features two types of firms: final-good producing firms and intermediate-good producing firms. The output of the final-good firm, Y_t, is packaged from a bundle of differentiated goods, $Y_t(j)$, produced by a continuum of intermediate-good producing firms indexed over $j \in [0,1]$ in accordance with a CES aggregator:

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{1}{1+\zeta_t^p}} di \right)^{1+\zeta_t^p} \tag{2.10}$$

where ζ_t^p denotes the elasticity of substitution among intermediate-firm output. We introduce price mark-up shocks into our analysis by assuming that ζ_t^p follows an ARMA(1,1) process[10] that is identical to the form assumed for ζ_t^w. Final-good firms, operating in perfectly competitive markets, seek to maximise profits subject to the technology constraint in

[10] As discussed by Smets and Wouters (2007), the motivation for including an MA term is that it allows the model to better capture the high frequency component in inflation fluctuations.

(2.10). The solution to the final-good firm's problem yields the familiar demand function presented below.

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\frac{1+\zeta_t^p}{\zeta_t^p}} Y_t \tag{2.11}$$

2.2.4 Intermediate-Good Firms

Production by the intermediate-good firm is undertaken by means of a Cobb-Douglas production function:

$$Y_t(j) = \zeta_t^a K_t(j)^\alpha \left(\gamma^t H_t(j)\right)^{1-\alpha} \tag{2.12}$$

where α is a share parameter, ζ_t^a denotes the stock of TFP and γ^t is defined as the exogenous labour-augmenting technological progress[11].

Furthermore, we assume that intermediate firms sell their output in a monopolistically competitive market subject to a Calvo (1983) constraint. For the fraction θ_p of intermediate firms unable to re-optimise their price, we assume the following indexation rule:

$$p_{t+k}(j) = \prod_{n=1}^{k} \frac{\Pi^{1-\iota_p}\Pi_{t-1,t-1+n}^{\iota_p}}{\Pi_{t,t+n}} p_t(j) \tag{2.13}$$

Those intermediate firms able to re-optimise will pick a price consistent with maximising the following optimisation problem subject to the demand constraint (2.11):

$$\max_{p_t(j)} E_t \sum_{k=0}^{\infty} (\theta_p)^k \Lambda_{t,t+k}(i) \left\{ \left(\prod_{n=1}^{k} \frac{\Pi^{1-\iota_p}\Pi_{t-1,t-1+n}^{\iota_p}}{\Pi_{t,t+n}} p_t(j) - MC_{t+k}(j) \right) Y_{t+k}(j) \right\} \tag{2.14}$$

where MC_t denotes the marginal cost function of the intermediate-good firm:

$$MC_t = \frac{W_t^{1-\alpha}\left(R_{t-1,t}^k\right)^\alpha}{\alpha\zeta_t^a \gamma^{(1-\alpha)t}(1-\alpha)^{(1-\alpha)}} \tag{2.15}$$

[11] Similar to Smets and Wouters (2007), we assume that the process for labour-augmenting technological change is deterministic.

Since the intermediate-good firm is ultimately owned by the household future profits are therefore discounted by the household stochastic discount factor.

2.2.5 Government

The Government budget constraint is given by:

$$G_t + \frac{B^N_{1,t-1}}{P_t} + \sum_{j=2}^{40} \frac{\mathfrak{P}^N_{j-1,t} B^N_{j,t-1}}{P_t} = \frac{B^N_{1,t}}{\zeta^b_t R_{t,t+1} P_t} + \sum_{j=2}^{40} \frac{\mathfrak{P}^N_{j,t} B^N_{j,t}}{P_t} + T_t \tag{2.16}$$

where G_t is indicative of exogenous government spending shocks which, as in Smets and Wouters (2007), respond to developments in domestic TFP. Exogenous spending is funded through the issuance of nominal bonds and the setting of a lump-sum tax.
Monetary policy is set through a Taylor-type rule in which the central bank reacts positively to inflation, the output gap and its first difference.

$$\frac{R_{t,t+1}}{R} = \left(\frac{R_{t-1,t}}{R}\right)^{\iota_r} \left(\left(\frac{\Pi_{t-1,t}}{\Pi}\right)^{\phi_\Pi} \left(\frac{Y_t}{Y^f_t}\right)^{\phi_y}\right)^{1-\iota_r} \left(\frac{Y_t/Y_{t-1}}{Y^f_t/Y^f_{t-1}}\right)^{\phi_{\Delta y}} \zeta^r_t \tag{2.17}$$

Potential output, Y^f_t, in our model is defined as that level of output that would pertain in the absence of mark-up shocks and flexible wages and prices. We also permit a role for interest rate inertia and monetary policy shocks denoted respectively by ι_r and ζ^r_t.

2.2.6 Market Clearing

Combining the Government's budget constraint with that of the households and making use of the zero-profit condition for both the labour packer and the final-good firm yields the aggregate resource constraint:

$$Y_t = C_t + I_t + G_t + F(U_t) K_{t-1} \tag{2.18}$$

2.2.7 Solution Method

The assumption of labour-augmenting technological progress implies that, along the balanced growth path, Y_t, C_t, I_t, K_{t-1} and W_t are all trending at an equivalent rate. We therefore render trending variables stationary via the following transformation: $\bar{X}_t = X_t/\gamma^t$. The model's solution is then approximated by log-linearising the equilibrium equations around the non-stochastic steady state.

2.2.8 News Shocks

To introduce news shocks into our analysis consider, for example, the law of motion assumed for the TFP shock:

$$\ln \zeta_t^a = \rho_a \ln \zeta_{t-1}^a + \eta_{t,a}^0 + \eta_{t,a}^j \tag{2.19}$$

In addition to the standard unanticipated TFP shock, $\eta_{t,a}^0$, (2.19) permits a role for an anticipated shock, $\eta_{t,a}^j$, that, if expected today, materialises in j periods time. The standard deviation of the innovation $\eta_{t,a}^j$ is mean zero and is uncorrelated with the unanticipated innovation and across time i.e. $E\left[\eta_{t,a}^j \eta_{t,a}^0\right] = 0$ and $E\left[\eta_{t,a}^j \eta_{t-m,a}^j\right] = 0$ for $m > 0$. Details on how j is set are deferred to section 2.3. In terms of the information structure assumed here we opt for simplicity and follow the formulation presented in Christiano et al. (2007) and subsequently Guo (2011). Specifically, we assume that news is anticipated perfectly in that there is no noise surrounding the signal that agent's receive. Furthermore, we assume that there is no TFP diffusion, TFP is set to increase only at the date of the news shock being realised[12]. Finally, we assume that the news shock is not subject to revisions as agent's gather more information about the signal. Of course we could allow for a richer information structure[13] but we feel that the one currently assumed does not detract away from our main point of enquiry which is to investigate the extent to which developments in the term spread

[12]See Comin et al. (2009) for a model in which technology diffusion is more rigorously considered.

[13]For example, the information structure presented in Schmitt-Grohé and Uribe (2012) allow for the possibility that agents are able to update the original signal as more information is gathered.

lead economic growth conditional on favourable news concerning the future state of output.

2.2.9 Asset Pricing

In pricing the nominal term structure, we exploit the recursive nature of the fundamental asset pricing equation central to the C-CAPM framework. Assuming no-arbitrage, the Euler equation used in the pricing of nominal bonds is given by:

$$\mathfrak{P}^N_{j,t} = E_t\left[\Lambda_{t,t+1}\mathfrak{P}^N_{j-1,t+1}\right] \tag{2.20}$$

In keeping with tantamount studies, we assume that, upon maturity, each bond will pay out one unit of currency. Exploiting the recursive nature of (2.20), we can price the entire nominal term structure by chaining the stochastic discount factor as demonstrated below:

$$\begin{bmatrix} \mathfrak{P}^N_{1,t} \\ \mathfrak{P}^N_{2,t} \\ \vdots \\ \mathfrak{P}^N_{40,t} \end{bmatrix} = E_t \begin{bmatrix} \frac{\Lambda_{t,t+1}}{\Pi_{t,t+1}} \cdot 1 \\ \frac{\Lambda_{t,t+1}}{\Pi_{t,t+1}} \cdot \mathfrak{P}^N_{1,t+1} \\ \vdots \\ \frac{\Lambda_{t,t+1}}{\Pi_{t,t+1}} \cdot \mathfrak{P}^N_{39,t+1} \end{bmatrix} = \begin{bmatrix} e^{-1\cdot\mathfrak{Y}^N_{1,t}} \\ e^{-2\cdot\mathfrak{Y}^N_{2,t}} \\ \vdots \\ e^{-40\cdot\mathfrak{Y}^N_{40,t}} \end{bmatrix} \tag{2.21}$$

where, for example, $\mathfrak{Y}^N_{j,t}$ denotes the continuously compounded yield on the j-period bond. We then define the term spread, TS_t, as the difference between the 40 and 1 quarter nominal continuously compounded spot rates:

$$TS_t = \mathfrak{Y}^N_{40,t} - \mathfrak{Y}^N_{1,t} \tag{2.22}$$

2.3 Estimation

Prior to the estimation of our model, we calibrate a subset of parameters that are notoriously difficult to identify. In particular, we set ζ^p and ζ^w both at 10 to hit a price and wage mark-up of both 10% in the steady state. The rate of depreciation, δ, is calibrated at 0.025, implying an annual depreciation rate of 10%. The rest of the model's parameters are estimated on the following vector of observables:

$$\mathbf{Y_t} = \begin{bmatrix} \Delta \ln \mathrm{CONS}_t \\ \Delta \ln \mathrm{GDP}_t \\ \Delta \ln \mathrm{WAG}_t \\ \Delta \ln \mathrm{INV}_t \\ \ln \mathrm{HOURS}_t \\ \mathrm{INF}_t \\ \mathrm{FEDFUNDS}_t \\ \mathrm{TERMSPREAD}_t \end{bmatrix}$$

In keeping with Smets and Wouters (2007), we include information on: the log difference of real consumption, the log difference of real output, the log difference of real wages, the log difference of real investment, the log of hours worked, the log difference of the GDP deflator and the federal funds rate. A key addition to our model is that we include the term spread in the measurement equation so that we can uncover, in a structural sense, those innovations most important in explaining term spread fluctuations. We construct the term spread by subtracting the 3-month Treasury bill rate from the 10-year Treasury bond rate. The data set is of quarterly frequency and spans from 1966:1 - 2004:4. The measurement equation in which we map our vector of observables to their model counterparts[14] is presented below:

$$\mathbf{Y_t}' = \begin{bmatrix} \Delta \ln \mathrm{CONS}_t \\ \Delta \ln \mathrm{GDP}_t \\ \Delta \ln \mathrm{WAG}_t \\ \Delta \ln \mathrm{INV}_t \\ \ln \mathrm{HOURS}_t \\ \mathrm{INF}_t \\ \mathrm{FEDFUNDS}_t \\ \mathrm{TERMSPREAD}_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{H} \\ \bar{\Pi} \\ \bar{R} \\ \bar{\mathfrak{c}} \end{bmatrix} + \begin{bmatrix} \tilde{C}_t - \tilde{C}_{t-1} \\ \tilde{Y}_t - \tilde{Y}_{t-1} \\ \tilde{W}_t - \tilde{W}_{t-1} \\ \tilde{I}_t - \tilde{I}_{t-1} \\ \tilde{H}_t \\ \tilde{\Pi}_{t-1,t} \\ \tilde{R}_{t,t+1} \\ \tilde{\mathfrak{Y}}^N_{40,t} - \tilde{\mathfrak{Y}}^N_{1,t} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \eta^m_t \end{bmatrix} \tag{2.23}$$

where $\bar{\gamma} = 100 \cdot (\gamma - 1)$ denotes the trend growth rate of the economy, $\bar{H}$ is the steady state of hours worked, $\bar{\Pi} = 100 \cdot (\Pi - 1)$ represents the steady state rate of inflation and $\bar{R} = 100 \cdot (\gamma^{\sigma_c}\beta^{-1}\Pi - 1)$ represents the steady state nominal interest rate and $\bar{\mathfrak{c}}$ denotes the level of the term spread in steady state. Following De Graeve et al. (2009), we attach a measurement error onto the measurement equation associated with the term spread. This is motivated on the basis that bond yields reflect both expectations regarding the stance of future monetary policy and risk premia.[15]

The Bayesian methodology employed in this paper combines the prior density of our parameter vector, $p(\Theta)$, with the likelihood function of our sample data, $L(\Theta|\mathbf{Y})$ to form the posterior density, $p(\Theta|\mathbf{Y})$.

$$p(\Theta|\mathbf{Y}) = \frac{p(\Theta)L(\Theta|\mathbf{Y})}{p(\mathbf{Y})} \tag{2.24}$$

One benefit of our estimation strategy is that it is a natural framework to test competing models which, for our purposes, will be utilised to pin down the optimal anticipation horizon for the anticipated TFP shock. By integrating both sides of (2.24) we can compare the marginal likelihood for each model that is differentiated by the anticipation horizon of the

[14]For notation, we let $\tilde{X}_t$ denotes the log-linearised counterpart of X_t.

[15]This point is discussed more thoroughly in the proceeding section. Furthermore, see Kim and Orphanides (2007) for an overview on term premia for US long-term yields.

news shock. Specifically, from (2.19), we estimate a battery of models for $j \in [0, 12]$ and compare the respective marginal likelihood for each model:

$$p(\mathbf{Y}|M^i) = \int p(\Theta^i|M^i)L(\Theta^i|\mathbf{Y}|, M^i)d\Theta^i \tag{2.25}$$

Consistent with maximising the value of (2.25), we set our anticipation horizon to 8 quarters.

2.4 Results

2.4.1 Parameter Estimates and Model Fit

Table 2.1 reports the mode of the posterior distribution for our benchmark model. For comparison, we also present estimates of a variant of our model which excludes the anticipated component of the TFP shock. However, as can be seen from Table 1, there is little difference in the estimates reported for the two models. To a great extent, this may be symptomatic of the relatively small estimate of the standard deviation reported for the anticipated TFP shock when compared against the other shock standard deviation estimates. Moreover, our estimate of 0.03 is one order of magnitude smaller than those estimates typically found in comparable studies (Fujiwara et al., 2011; Khan and Tsoukalas, 2012; Schmitt-Grohé and Uribe, 2012) which, at first glance, is suggestive of the relative unimportance our model attributes to the anticipated TFP shock. We do, however, find that our estimates obtained for the structural parameters in addition to those governing the other shock processes are well within the range reported in other studies considering medium scale New-Keynesian models (Smets and Wouters, 2007; Justiniano et al., 2010).

One way in which we can evaluate the fit of our model is to assess the standard deviation of the measurement error appended to the term spread observation equation. Inspection of Figure 2.2 is indicative of large deviations between the term spread implied by our model and that of the data. As such, the measurement error appears to be significant in our analysis, particularly during the 1980s. However, it is important to recognise that movements in the term spread may be the result of changes in the expected path of future short-term interest rates or changes to the quantity of term premia demanded by those investors holding long-term bonds. Thus, the term spread is more aptly defined as:

$$\mathfrak{Y}^N_{40,t} - \mathfrak{Y}^N_{1,t} = \left[\frac{1}{40}\sum_{k=0}^{39} E_t \left\{\mathfrak{Y}^N_{1,t,t+k}\right\} - \mathfrak{Y}^N_{1,t}\right] + \eta^m_t \tag{2.26}$$

where the first term on the RHS of (2.26) is consistent with the expectations hypothesis[16] (EH). The second term is representative of term premia. The estimation procedure employed in this analysis offers a natural way of decomposing the term spread into these two components. As discussed by Morell (2017), the estimation of linearised DSGE models will, by construction, impose the pure EH[17], such that the smoothed estimate of the term spread implied by our model will be driven solely by changes in the expected path of the short-term interest rate. Those term spread fluctuations that the model is unable to account for will be reflected through the measurement error which, given the discussion above, should serve as a proxy for term premia. Indeed, we find the correlation between the measurement error and the commonly quoted Kim and Wright (2005) estimate of the 10 year term premium to be 0.91[18]. Consequently, the significance of the measurement error is most likely to be reflective of developments in term premia as opposed to being indicative of poor model fit more generally. For instance, the peak in the measurement error during the late 1970s and early 1980s coincides with that period characterised by stable US real rates in addition to high and unstable rates of inflation. In such an environment, investors will prefer to invest in short-term bonds and will require positive term premia as compensation for investing in

[16]The EH implies that the expected excess return on long-term bonds over short-term bonds is constant over time and dependent upon maturity. In its purest form, the pure expectations hypothesis, says that these expected excess returns are zero (Lutz, 1940).

[17]See Schmitt-Grohé and Uribe (2004) for an overview on how linearised solution methods imply the certainty equivalence theorem and thereby restrict risk premia to be zero.

[18]We report correlations of a similar magnitude with other estimates of the 10 year term premium. Full results are available on request.

relatively riskier long-term bonds (Cochrane, 2007)[19]. Furthermore, the secular decline in the measurement error since the late 1980s is also consistent with the pattern observed for US term premia (Wright, 2011).

2.4.2 Transmission of the Anticipated TFP Shock

Figure 2.3 presents the impulses response functions associated with the anticipated TFP shock. Consistent with Jaimovich and Rebelo (2009) and Kurmann and Otrok (2013*a*), our model exibits positive impact co-movement among consumption, investment, hours and output. This result, however, stands in stark contrast to the predictions of the standard neo-classical economy considered in Barro and King (1984) which, for a long time, has constrained the importance of news shocks from a theoretical perspective. To see their result, consider the intra-temporal efficiency condition that the baseline neoclassical economy implies:

$$MRS(C,H) = \frac{U_H(C,H)}{U_C(C,H)} = MPL \tag{2.27}$$

whereby the rate at which agents are willing to trade leisure for consumption goods is equal to the marginal product of labour. The reception of good news about the future, through the wealth effect, will induce agents to increase today's consumption causing the LHS of (2.27) to increase[20]. Thus, in a frictionless neoclassical setting, hours must fall as to maintain the intra-temporal efficiency condition. An increase in consumption coupled with a decline in hours will, through the budget constraint, trigger a fall in investment and output.

Of course, this result is conditional on the marginal product of labour schedule remaining constant, for if the anticipated shock can generate an increase in the marginal product of labour, then the previous constraint need no longer bind - consumption, investment, hours and output may all increase on impact. In bringing about the necessary shift in the marginal

[19] This is because, relative to long-term bonds, short-term rates offer a better hedge against unstable inflation rates since they adapt much more quickly to developments in the inflation rate.

[20] $MRS_C(C,H) > 0$ and $MRS_C(C,H) > 0$

product of labour schedule, we find the inclusion of variable capacity utilisation and investment adjustment costs to be pivotal. However, since the use of capacity utilisation incurs a cost to firms, there must be a significant decrease in the value of installed capital, Tobin's Q, in order to incentivise firms to work their capital stock more intensely. As in Jaimovich and Rebelo (2009), investment adjustment costs are key here in effecting a sufficient fall in Tobin's Q, which in turn raises the marginal product of labour via the increase in capacity utilisation. Figure 2.4 illustrates the importance of adjustment costs in generating an expectation-led boom by comparing the impulse response functions of our benchmark model against those in which the costs of investment adjustment have been reduced significantly. The figure makes clear that in the absence of significant adjustment costs, output, hours and investment all decrease on impact despite the reception of favourable news concerning the future state of TFP. The intuition behind this result is that adjustment costs imply that it is no longer optimal to begin investing in 8 quarters time when the news shock realises. Rather, agents should effect their investment plans today and enter that period with higher levels of investment as to minimise the costs of adjustment. Investment smoothing augments the current capital stock, but since additional capital will only be justified when the news shock materialises, the value of installed capital begins to fall thus leading to the observed decrease in Tobin's Q. Firms will therefore work their capital stock more intensely in order to placate the additional demand brought about by the investment adjustment costs.

On the nominal side of the economy and contrast to the findings of Kurmann and Otrok (2013*a*), we observe an increase in inflation which, when coupled with the positive comovement of real aggregates, effects a rise in the policy rate causing the slope to decrease on impact. Such a response clearly conflicts with the notion that the term structure should, as a leading indicator, anticipate the incipient economic growth that a news shock engenders. Culpable, to a great extent, is the aforementioned positive response of inflation. The initial increase in inflation is largely due to the upward pressure investment adjustment costs enforce on aggregate demand. Moreover, since we assume no diffusion in TFP, TFP is not expected to change until the date in which the news shock materialises. As such, there will be no reduction in marginal costs to counteract the upward pressure on inflation until that date. The subsequent and sharp decline in the inflation rate is a consequence of the anticipated TFP shock realising. It is interesting to note that while investment adjustment costs are central to the positive co-movement result, they also accentuate the qualitative disparity of the term spread response relative to Kurmann and Otrok (2013*a*). In this regard, our findings echo those of Kurmann and Otrok (2013*b*)[21].

2.4.3 Variance Decompositions

To examine the quantitative importance of the anticipated TFP shock, we calculate the unconditional forecast error variance decomposition of our benchmark model evaluated at the posterior mean of our parameter estimates. Table 2.4 contains our results for the term spread alongside other selected variables. A key observation is the importance our model attributes to the monetary policy shock in explaining term spread variation, accounting for 43.6% of its variance[22]. Furthermore, our model also attaches importance to the wage and price mark-up shocks explaining 17.2% and 18.2 % of term spread variation respectively. Analysing the dynamic relationship between the term spread and output that these shocks imply yields great insight into our results. For example, from Figure 2.5, following a monetary policy shock, we observe that the initial increase in the policy rate attenuates up the term structure as evidenced by the reaction of long-term bond yields falling relatively less in comparison. Consequently, the term spread decreases significantly on impact. Due to higher interest rates, investment and consumption are cut back causing output growth to be negative in the proceeding periods. Furthermore, following both mark-up shocks, we observe a term spread that positively leads output growth. This is because the Central bank is forced to curtail

[21]The authours stipulate the conditions in which the New-Keynesian paradigm is able to manufacture a fall in inflation in response to a news shock. First, they propose that the initial pressure on aggregate demand must be modest. Second, the slope of the NKPC should not be excessive so that fluctuations in aggregate demand do not fully transmit through to inflation.

[22]Indeed, De Graeve et al. (2009) also find that the monetary policy shock accounts for a considerable share of the US term spread's variance.

the inflationary pressure implied by each mark-up shock by raising the policy rate and thus prompting an initial decline in the term spread. Similar to the monetary policy shock, the subsequent periods of negative output growth are consistent with the strong leading properties of the term spread in the data and explain why our model attributes a large share of the term spread's variance to each of these shocks. In stark contrast, the anticipated TFP shock is found to be of negligible importance in driving term spread fluctuations, accounting for only 0.15 % of the term spread's variance. By a similar argument, we can shed light on this result by examining Figure 2.3 once more to observe a term spread that is inconsistent with the data in that it does not positively lead output growth.

Moreover, our results are indicative of the limited contribution that the anticipated TFP shock plays in explaining the variance of the real side of the economy, accounting for only 0.07%, 0.09%, 0.26% and 0.07% of the variation in output, consumption, hours and investment respectively. We thus reach similar conclusions to those of Fujiwara et al. (2011), Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012) who also find limited support for the anticipated component in a stationary TFP shock.

2.5 Other Sources of News

Much of the literature on expectation-led business cycles has focussed on news strictly pertaining to technological progress. However, the contributions of, among others, Khan and Tsoukalas (2012) and Schmitt-Grohé and Uribe (2012) highlight the importance that news unrelated to technology may have in driving economic fluctuations. In this section, we examine the quantitative importance of other forms news in driving term spread fluctuations. To this end, we re-estimate our model after augmenting all other exogenous processes with an anticipated component. As in the case of our benchmark model, we consider an anticipation horizon of 8 quarters for all anticipated shocks. Table 2.3 reports the parameter estimates for this model alongside those estimates presented in Table 2.1 for comparative purposes. However, as can be observed from Table 2.3 we report little difference in the parameter estimates between all three models. To assess the importance of alternative sources of news, we report their relative contribution in explaining the variation of key series in Table 2.4. A key finding is that in spite of considering alternative anticipated shocks, it is still the unanticipated innovations that account for the bulk of variation in our macro series. Of particular interest is the term spread, we find that 86.3% of its variance is attributed to unanticipated shocks. However, we do report a role, albeit limited, for the anticipated price and wage mark-up shocks in that they account for 3.23% and 6.29% of term spread variation respectively. Indeed, more generally our results indicate that the anticipated mark-up shocks jointly explain a non-negligible share of the variance in all series, particularly that of wages, consumption and hours. In this regard, our findings are similar to those of Khan and Tsoukalas (2012) who also report the anticipated mark-up shocks to be the most important source of news. However, in contrast to our results, these authours find that for some aggregates, anticipated shocks are the dominant source of fluctuations. In particular, Khan and Tsoukalas (2012) find the news component of the wage mark-up shock to explain the majority of variation in hours and inflation, accounting for 59.9% and 59.4% of total variance respectively. A key difference in model design between our paper and Khan and Tsoukalas (2012) is that they consider the preference structure adopted in Greenwood et al. (1988). Specifically, Khan and Tsoukalas (2012) consider a preference structure of the form:

$$E_t \sum_{k=0}^{\infty} \beta^k \frac{\varepsilon_{t+k}^b \left(C_{t+k} - hC_{t+k-1} - \chi L_{t+k}^{1+\sigma_l} X_{t+k}\right)^{1-\sigma_c-1}}{1-\sigma_c} \tag{2.28}$$

where

$$X_t = \left(C_t - hC_{t-1}\right)^{\omega} X_{t-1}^{1-\omega} \tag{2.29}$$

where β is the subjective discount factor, ε_t^b is a preference shock, C_t denotes consumption, h is the internal habit parameter, χ is the weight on labour disutility, L_t denotes labour services, σ_l is the elasticity of labour supply, σ_c is the intertemporal elasticity of substitution and ω is a preference weight. As discuss by Khan and Tsoukalas (2012), when $\omega = 0$ the preferences presented in (2.28) resembles those of Greenwood et al. (1988). The implication of Greenwood et al. (1988) preferences is that the intertemporal consumption-savings decision has no impact on labour supply. Consequently, any favourable news about the future will not reduce labour supply under this form of preferences. Moreover, the preferences in (2.28) also nest the case of King et al. (1988) preferences when $\omega = 1$. Under King et al. (1988) preferences, the intertemporal consumption-savings decision will impact labour supply. Upon estimating their model, Khan and Tsoukalas (2012) obtain an estimate of ω in which the impact of inter-temporal substitution on labour effort is partially offset. As such, Khan and Tsoukalas (2012) find that their model is able to generate aggregate comovement in response to many anticipated shocks - a key feature observed empirically. This is found to be key in propagating the anticipated mark-up shocks in Khan and Tsoukalas (2012)'s analysis.

2.6 Conclusion

This paper has examined the quantitative importance of anticipated TFP shocks in driving US term spread fluctuations. Our analysis was conducted using a medium-scale DSGE model estimated on US data. Our main conclusion is that the anticipated component in the TFP shock is found to be negligible in explaining variations of key macro aggregates. In particular, we report that the TFP news shock accounts for less than 1% of the term spread's variance. To a great extent, this result is symptomatic of the inability of our model to mimic the term structure response to an anticipated TFP shock found in the data (Kurmann Otrok, 2012). A key finding of our paper is that in the absence of technology diffusion, positive comovement in real aggregates drives up marginal costs and thereby inflation causing the term spread to decline on impact via an endogenous monetary tightening. Future research could therefore be directed towards augmenting the industry-standard DSGE model with a rigorous process of technology diffusion. This would provide a micro-founded way of bringing the TFP and inflation response closer to the data.

This paper also examined the importance of other forms of news by incorporating an anticipated component on each of the other structural shocks. We found, however, that when both anticipated and unanticipated shocks compete within the same model, the unanticipated shocks account for the dominant share in the variation of key macro aggregates.

2.7 Tables

Table 2.1: Prior and Posterior Distributions

		Prior			Posterior (A)		Posterior (B)	
Parameter	Description	Density	Mean	Std.	Mode	Std.	Mode	Std.
$100 \cdot \left(\frac{1}{\beta} - 1\right)$	Discount factor	G	0.25	0.10	0.16	0.06	0.16	0.06
$100 \cdot (\gamma_* - 1)$	Trend growth	N	0.40	0.10	0.43	0.02	0.43	0.02
$100 \cdot (\Pi - 1)$	Trend inflation	G	0.80	0.10	0.81	0.09	0.81	0.09
H_*	SS hours	N	0.00	2.00	1.05	1.45	1.02	1.54
$\mathfrak{C}$	Constant	N	0.25	0.10	0.33	0.08	0.32	0.08
σ_c	I.E.I.S	N	1.50	0.37	1.28	0.16	1.33	0.16
σ_h	Elast. lab. supply	N	2.00	0.75	1.57	0.56	1.47	0.55
ι_c	Cons. habit	B	0.70	0.10	0.79	0.04	0.77	0.04
γ_w	Wage indexation	B	0.50	0.15	0.59	0.14	0.60	0.14
θ_w	Calvo wages	B	0.50	0.10	0.81	0.03	0.81	0.03
χ	Utilisation cost	B	0.50	0.15	0.42	0.13	0.44	0.13
Φ''	IA cost	N	4.00	1.50	5.99	1.05	5.86	1.05
α	Capital share	N	0.30	0.05	0.18	0.02	0.19	0.02
γ_p	Price indexation	B	0.50	0.15	0.20	0.08	0.20	0.08
θ_p	Calvo prices	B	0.50	0.10	0.81	0.03	0.80	0.03
ϕ_π	TR. Inflation	N	1.50	0.25	1.68	0.18	1.70	0.18
ϕ_y	TR. output	N	0.12	0.05	0.06	0.03	0.06	0.03
$\phi_{\Delta y}$	TR. Δ output	N	0.12	0.05	0.21	0.05	0.21	0.05
γ_i	TR. smoothing	N	0.75	0.10	0.73	0.04	0.72	0.04
ρ_b	AR(1) Preference	B	0.50	0.20	0.14	0.07	0.14	0.08
ρ_z	AR(1) Inv-specific	B	0.50	0.20	0.72	0.07	0.72	0.06
ρ_a	AR(1) TFP	B	0.50	0.20	0.96	0.01	0.97	0.01
ρ_m	AR(1) Mon. Pol	B	0.50	0.20	0.28	0.08	0.28	0.08
ρ_g	AR(1) Govt.	B	0.50	0.20	0.99	0.01	0.98	0.01
$\rho_{a,g}$	AR(1) TFP/Govt.	B	0.50	0.25	0.55	0.06	0.52	0.06
ρ_p	AR(1) P.M up	B	0.50	0.20	0.94	0.04	0.95	0.03
ρ_w	AR(1) W.M up	B	0.50	0.20	0.98	0.01	0.98	0.01
Θ_p	MA(1) P.M up	B	0.50	0.20	0.71	0.08	0.71	0.08
Θ_w	MA(1) W.M up	B	0.50	0.20	0.78	0.08	0.77	0.08
σ_b	Std. Preference	IG	0.10	2.00	0.26	0.02	0.26	0.02
σ_z	Std. Inv-specific	IG	0.10	2.00	0.40	0.05	0.41	0.05
σ_a	Std. TFP	IG	0.10	2.00	0.61	0.04	0.63	0.04
σ_g	Std. Govt'	IG	0.10	2.00	0.46	0.03	0.47	0.03
σ_r	Std. Mon. Pol	IG	0.10	2.00	0.27	0.02	0.27	0.02
σ_p	Std. P.M up	IG	0.10	2.00	0.14	0.02	0.14	0.02
σ_w	Std. W.M up	IG	0.10	2.00	0.26	0.03	0.26	0.03
σ_a	Std. TFP (news)	IG	0.10	2.00	0.03	0.01	-	-
σ_m	Std. Measurement	U	2.00	2.00	0.66	0.04	0.65	0.04

Notes: a. Model (A) corresponds to our benchmark model which is inclusive of the anticipated component in the TFP shock process. Model (B) is exclusive of news shocks.

Table 2.2: Variance Decompositions

	Shock							
	ζ_t^b	ζ_t^i	ζ_t^a	ζ_t^r	ζ_t^g	ζ_t^p	ζ_t^w	ζ_{t-8}^a
Output	17.9	9.37	24.8	7.38	11.7	9.00	19.8	0.07
Inflation	3.12	5.18	8.66	6.93	0.88	45.1	33.4	0.15
Consumption	38.1	0.81	6.12	12.5	4.20	9.51	28.7	0.09
Real Wage	5.41	3.38	14.1	5.95	0.59	37.1	33.4	0.15
Investment	1.28	73.5	8.32	1.33	0.89	4.19	10.4	0.07
Hours	21.8	11.4	6.89	8.49	14.8	8.53	27.8	0.26
Policy Rate	5.50	6.64	7.65	43.6	1.11	18.2	17.2	0.15
1 Year Yield	6.18	7.93	8.69	35.7	1.32	19.4	20.6	0.16
5 Year Yield	5.56	6.73	7.73	43.0	1.13	18.3	17.5	0.15
10 Year Yield	5.53	6.68	7.69	43.3	1.12	18.2	17.3	0.15
Term Spread	5.50	6.64	7.65	43.6	1.11	18.2	17.2	0.15

Notes: a. Forecast error variance decompositions at the infinite horizon evaluated at the posterior mode obtained for Model (A). The entries correspond to the relative contribution of each shock denoted in percent. Due to rounding, each row may not sum to 100.
b. Where ζ^b: preference, ζ^i: investment, ζ^a: TFP, ζ^r: monetary policy, ζ^g: Govt', ζ^p: price mark-up, ζ^w: wage mark-up.

Table 2.3: Prior and Posterior Distributions

		Prior			Posterior (A)		Posterior (B)		Posterior (C)	
Parameter	Description	Density	Mean	Std.	Mode	Std.	Mode	Std.	Mode	Std.
$100 \cdot \left(\frac{1}{\beta} - 1\right)$	Discount factor	G	0.25	0.10	0.16	0.06	0.16	0.06	0.15	0.06
$100 \cdot (\gamma_* - 1)$	Trend growth	N	0.40	0.10	0.43	0.02	0.43	0.02	0.45	0.02
$100 \cdot (\Pi - 1)$	Trend inflation	G	0.80	0.10	0.81	0.09	0.81	0.09	0.75	0.09
H_*	SS hours	N	0.00	2.00	1.05	1.45	1.02	1.54	1.37	1.30
$\mathfrak{C}$	Constant	N	0.25	0.10	0.33	0.08	0.32	0.08	0.34	0.08
σ_c	I.E.I.S	N	1.50	0.37	1.28	0.16	1.33	0.16	1.40	0.15
σ_h	Elast. lab. supply	N	2.00	0.75	1.57	0.56	1.47	0.55	1.97	0.62
ι_c	Cons. habit	B	0.70	0.10	0.79	0.04	0.77	0.04	0.79	0.03
γ_w	Wage indexation	B	0.50	0.15	0.59	0.14	0.60	0.14	0.49	0.14
θ_w	Calvo wages	B	0.50	0.10	0.81	0.03	0.81	0.03	0.87	0.02
χ	Utilisation cost	B	0.50	0.15	0.42	0.13	0.44	0.13	0.38	0.12
Φ''	IA cost	N	4.00	1.50	5.99	1.05	5.86	1.05	5.90	1.02
α	Capital share	N	0.30	0.05	0.18	0.02	0.19	0.02	0.18	0.02
γ_p	Price indexation	B	0.50	0.15	0.20	0.08	0.20	0.08	0.17	0.07
θ_p	Calvo prices	B	0.50	0.10	0.81	0.03	0.80	0.03	0.81	0.03
ϕ_π	TR. Inflation	N	1.50	0.25	1.68	0.18	1.70	0.18	1.72	0.16
ϕ_y	TR. output	N	0.12	0.05	0.06	0.03	0.06	0.03	0.10	0.03
$\phi_{\Delta y}$	TR. Δ output	N	0.12	0.05	0.21	0.05	0.21	0.05	0.21	0.05
γ_i	TR. smoothing	N	0.75	0.10	0.73	0.04	0.72	0.04	0.77	0.03
ρ_b	AR(1) Preference	B	0.50	0.20	0.14	0.07	0.14	0.08	0.14	0.08
ρ_z	AR(1) Inv-specific	B	0.50	0.20	0.72	0.07	0.72	0.06	0.66	0.06
ρ_a	AR(1) TFP	B	0.50	0.20	0.96	0.01	0.97	0.01	0.97	0.01
ρ_m	AR(1) Mon. Pol	B	0.50	0.20	0.28	0.08	0.28	0.08	0.23	0.08
ρ_g	AR(1) Govt.	B	0.50	0.20	0.99	0.01	0.98	0.01	0.99	0.01
$\rho_{a,g}$	AR(1) TFP/Govt.	B	0.50	0.25	0.55	0.06	0.52	0.06	0.56	0.06
ρ_p	AR(1) P.M up	B	0.50	0.20	0.94	0.04	0.95	0.03	0.94	0.04
ρ_w	AR(1) W.M up	B	0.50	0.20	0.98	0.01	0.98	0.01	0.97	0.03
Θ_p	MA(1) P.M up	B	0.50	0.20	0.71	0.08	0.71	0.08	0.86	0.07
Θ_w	MA(1) W.M up	B	0.50	0.20	0.78	0.08	0.77	0.08	0.94	0.03
σ_b	Std. Preference	IG	0.10	2.00	0.26	0.02	0.26	0.02	0.26	0.02
σ_z	Std. Inv-specific	IG	0.10	2.00	0.40	0.05	0.41	0.05	0.44	0.05
σ_a	Std. TFP	IG	0.10	2.00	0.61	0.04	0.63	0.04	0.61	0.04
σ_g	Std. Govt'	IG	0.10	2.00	0.46	0.03	0.47	0.03	0.45	0.03
σ_r	Std. Mon. Pol	IG	0.10	2.00	0.27	0.02	0.27	0.02	0.26	0.02
σ_p	Std. P.M up	IG	0.10	2.00	0.14	0.02	0.14	0.02	0.17	0.02
σ_w	Std. W.M up	IG	0.10	2.00	0.26	0.03	0.26	0.03	0.27	0.02
σ_b^8	Std. Preference (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_z^8	Std. Inv.Spec (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_a^8	Std. TFP (news)	IG	0.07	2.00	0.03	0.01	-	-	0.03	0.02
σ_g^8	Std. Govt' (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_r^8	Std. Mon.Pol (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_p^8	Std. P.M.Up (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_w^8	Std. W.M.Up (news)	IG	0.07	2.00	-	-	-	-	0.03	0.01
σ_m	Std. Measurement	U	2.00	2.00	0.66	0.04	0.65	0.04	0.66	0.04

Notes: Model (C) corresponds to the model with an anticipated component in each of the structural shocks.

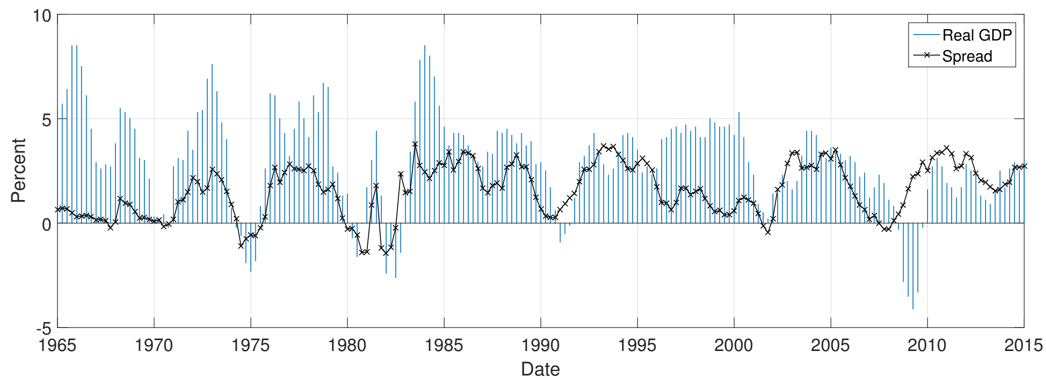
Table 2.4: Variance Decompositions

	Unanticipated Shocks							
	ζ_t^b	ζ_t^i	ζ_t^a	ζ_t^r	ζ_t^g	ζ_t^p	ζ_t^w	Total
Output	18.6	10.3	30.0	8.56	12.4	2.23	2.67	84.8
Inflation	2.68	4.97	15.3	7.74	0.95	36.9	10.7	79.2
Consumption	42.5	0.20	8.79	15.4	4.97	2.62	4.19	78.7
Real Wage	2.74	2.68	21.2	3.88	0.38	11.2	25.6	67.7
Investment	1.68	70.9	11.4	1.93	1.06	0.98	1.34	89.3
Hours	24.3	13.3	8.74	10.7	16.6	2.24	3.85	79.7
Policy Rate	5.30	6.03	10.5	51.3	1.19	7.39	4.55	86.3
1 Year Yield	6.14	7.38	12.3	43.6	1.45	7.35	5.44	83.7
5 Year Yield	5.37	6.12	10.7	50.7	1.21	7.40	4.62	86.1
10 Year Yield	5.33	6.07	10.6	51.0	1.20	7.40	4.58	86.2
Term Spread	5.30	6.03	10.5	51.3	1.19	7.39	4.55	86.3
	Anticipated Shocks							
	ζ_{t-8}^b	ζ_{t-8}^i	ζ_{t-8}^a	ζ_{t-8}^r	ζ_{t-8}^g	ζ_{t-8}^p	ζ_{t-8}^w	Total
Output	1.61	0.11	0.02	0.10	0.08	3.37	10.3	15.2
Inflation	2.67	0.05	0.04	0.46	0.01	6.30	11.2	20.8
Consumption	2.43	0.09	0.03	0.14	0.03	3.21	15.5	21.3
Real Wage	1.21	0.04	0.04	0.11	0.02	17.7	13.2	32.3
Investment	0.84	0.93	0.02	0.07	0.01	3.33	6.48	32.3
Hours	1.94	0.13	0.08	0.12	0.11	3.15	14.9	10.7
Policy Rate	3.17	0.06	0.04	1.01	0.02	3.23	6.29	13.7
1 Year Yield	3.87	0.07	0.05	0.89	0.03	3.59	7.97	16.3
5 Year Yield	3.21	0.06	0.04	0.99	0.02	3.26	6.40	13.9
10 Year Yield	3.19	0.06	0.04	1.00	0.02	3.24	6.34	13.8
Term Spread	3.16	0.06	0.04	1.01	0.02	3.23	6.29	13.7

Notes: a. Forecast error variance decompositions at the infinite horizon evaluated at the posterior mode obtained for Model (C). The entries correspond to the relative contribution of each shock denoted in percent. Due to rounding, each row may not sum to 100.
b. Where ζ^b: preference, ζ^i: investment, ζ^a: TFP, ζ^r: monetary policy, ζ^g: Govt', ζ^p: price mark-up, ζ^w: wage mark-up.

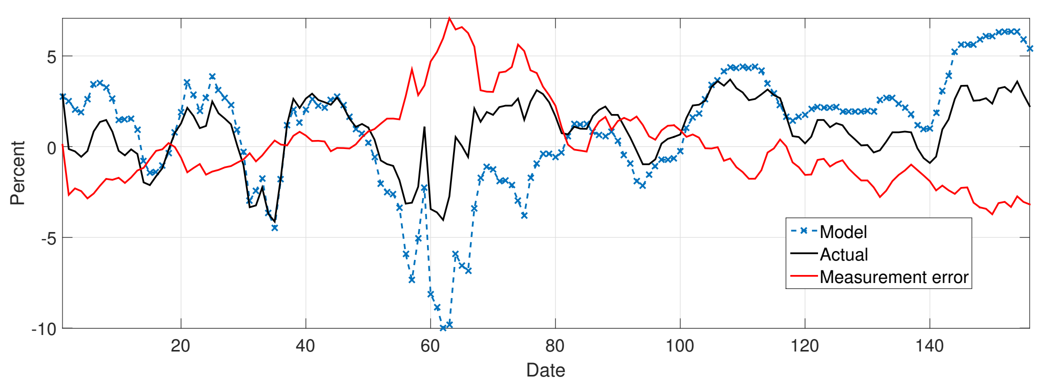
2.8 Figures

Figure 2.1: Term Spread and Real GDP Growth



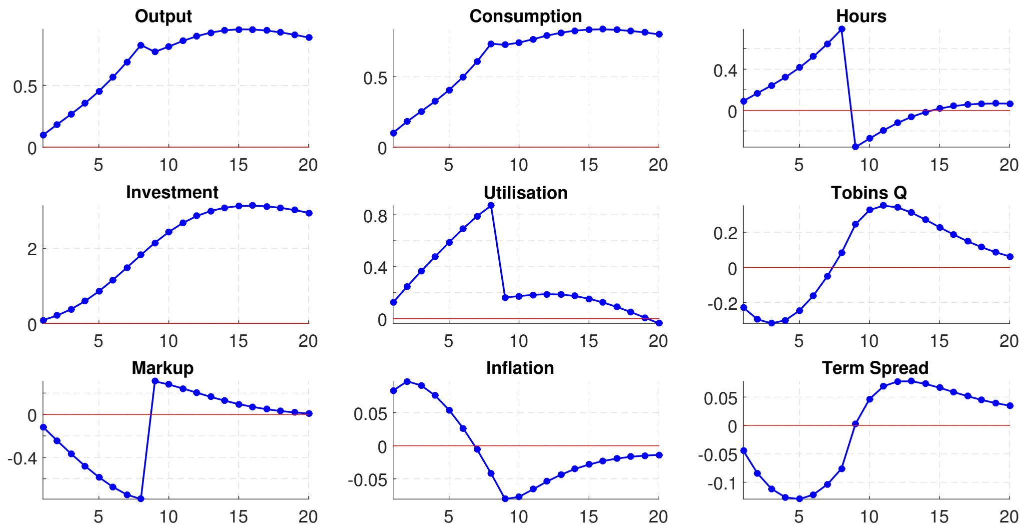
Notes: The spread is constructed by subtracting the 3-month Treasury bill rate from the 10-year Treasury bond rate. The output series is defined as the annualised percentage change in real GDP. Both series are expressed at an annual rate and can be obtained from FRED.

Figure 2.2: Term Spread Fit



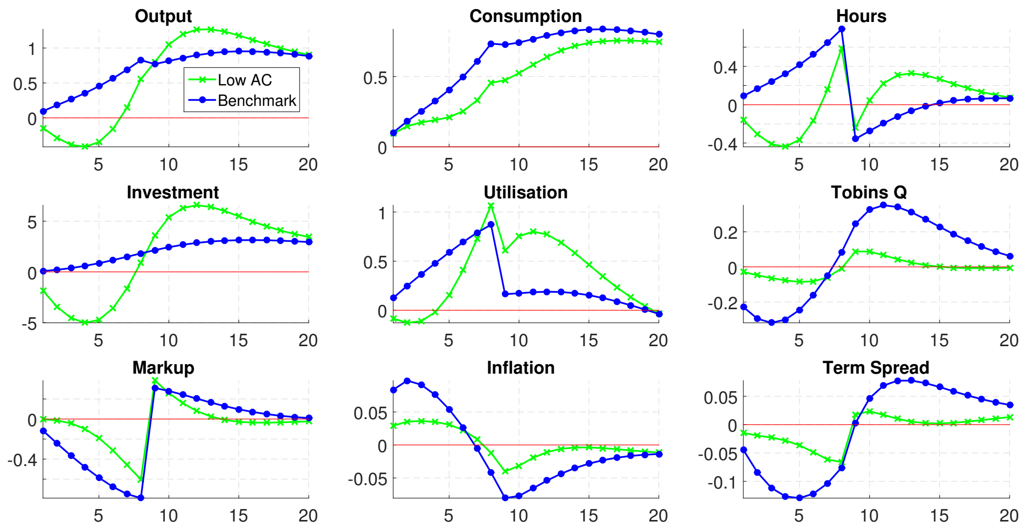
Notes: We present the term spread series computed from the data alongside the smoothed estimates implied by our model. The difference between these two series is reflected by the measurement error.

Figure 2.3: Impulse Response Functions: $\zeta^a_{t-8} \uparrow$



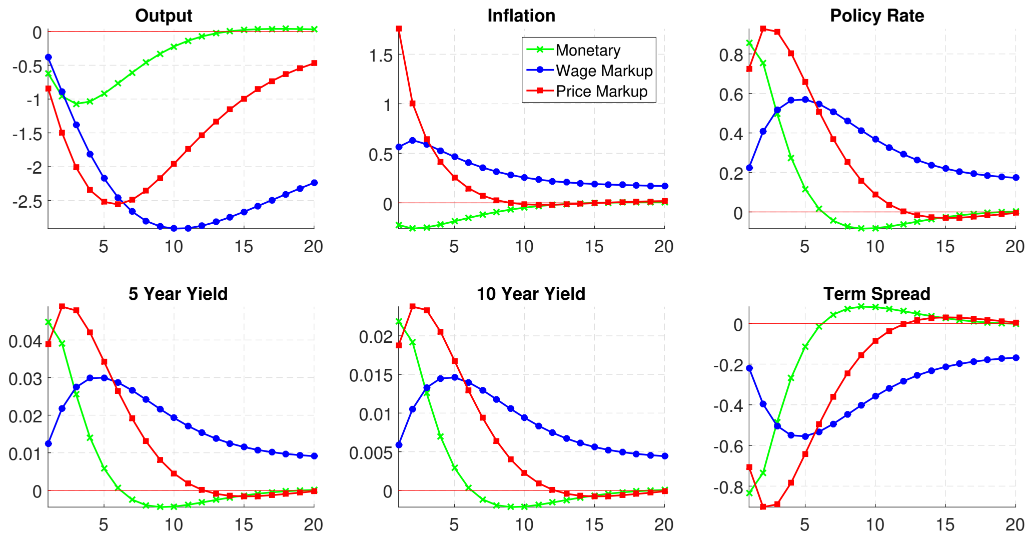
Notes: Impulse response functions to an anticipated TFP shock. The impulse responses are computed using the mode of the posterior distribution. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 2.4: Impulse Response Functions: $\zeta^a_{t-8} \uparrow$



Notes: Impulse response functions to an anticipated TFP shock. The benchmark impulse responses are computed using the mode of the posterior distribution. Impulses presented for the Low AC model correspond to a specification in which we change only the investment adjustment cost parameter, Φ'', from 5.99 to 0.1. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 2.5: Impulse Response Functions: $\zeta_t^r \uparrow, \zeta_t^w \uparrow, \zeta_t^p \uparrow$



Notes: Impulse response functions to the monetary, wage mark-up and price mark-up shocks. The impulse responses are all computed using the mode of the posterior distribution. The y-axis denotes percentage deviations from steady state and the x-axis denotes the quarters elapsed following the shock.

2.9 Appendices

2.A Data

Definition of observable variables used in the estimation:

- Output $= \ln(\text{GDPC1}/\text{LNSindex}) * 100$
- Consumption $= \ln((\text{PCEC}/\text{GDPDEF})/\text{LNSindex}) * 100$
- Investment $= \ln((\text{FPI}/\text{GDPDEF})/\text{LNSindex}) * 100$
- Hours $= \ln((\text{PRS85006023} * \text{CE16OV}/100)/\text{LNSindex}) * 100$
- Real Wage $= \ln(\text{PRS85006103}/\text{GDPDEF}) * 100$
- Inflation $= \ln(\text{GDPDEF}/\text{GDPDEF}(-1)) * 100$
- Interest Rate = FEDFUNDS / 4
- Term Spread = (DGS10 - TB3MS) / 4

Source of original data:

- GDPC1: Real Gross Domestic Product - Billions of Chained 2009 Dollars, Seasonally Adjusted Annual Rate.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- LNS11000000: Civilian Labor Force Status : Civilian no-institutional population - Age: 16 years and over -Seasonally Adjusted - Number in thousands.

  Source: U.S. Bureau of Labor Statistics.

- LNSindex: LNS10000000(1992:3) = 1.

- PCEC: Personal Consumption Expenditures - Billions of Dollars, Seasonally Adjusted Annual Rate.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- GDPDEF: Gross Domestic Product - Implicit Price Deflator - 2009=100, Seasonally Adjusted.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- FPI: Fixed Private Investment - Billions of Dollars, Seasonally Adjusted Annual Rate.

  Source: U.S. Department of Commerce, Bureau of Economic Analysis.

- PRS85006103: Non-farm Business, All Persons, Hourly Compensation Duration: index, 2009 =100, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- CE16OV: Civilian Employment: Sixteen Years & Over, Thousands, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- CE16OV index: CE16OV (1992:3)=1

- PRS85006103: Non-farm Business, All Persons, Hourly Compensation Duration: index, 2009 =100, Seasonally Adjusted.

  Source: U.S. Bureau of Labor Statistics

- FEDFUNDS: Averages of Daily Figures - Percent.

  Source: Board of Governors of the Federal Reserve System (Before 1954: 3-Month Treasury Bill Rate, Secondary Market Averages of Business Days, Discount Basis)

- DGS10: 10 Year Treasury Constant Maturity Rate, Not Seasonally Adjusted, Percent.

  Source: Board of Governors of the Federal Reserve System.

- TB3MS: 3 Month Treasury Constant Maturity Rate, Not Seasonally Adjusted, Percent.

  Source: Board of Governors of the Federal Reserve System.

2.B Stationary Non-Linear System

<u>*Sticky-Price Economy:*</u>

1. $\lambda_t = (C_t - \iota_c C_{t-1})^{-\sigma_c} \exp\left\{\frac{\sigma_c - 1}{1+\sigma_h} H_t^{1+\sigma_h}\right\}$

2. $\lambda_t = \bar{\beta}\eta_t^b R_{t,t+1} E_t \left[\frac{\lambda_{t+1}}{\Pi_{t,t+1}}\right]$
   where $\bar{\beta} = \beta\gamma^{-\sigma_c}$

3. $1 = Q_t \eta_t^i \left(1 - \Phi\left(\frac{t}{I_{t-1}}\right) - \Phi'\left(\frac{\gamma I_t}{I_{t-1}}\right)\left(\frac{\gamma I_t}{I_{t-1}}\right)\right) + \bar{\beta} E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \eta_{t+1}^i Q_{t+1} \Phi'\left(\frac{\gamma I_{t+1}}{I_t}\right)\left(\frac{\gamma I_{t+1}}{I_t}\right)^2\right]$

4. $Q_t = \bar{\beta} E_t \left[Q_{t+1}(1-\delta) + \frac{\lambda_{t+1}}{\lambda_t}\left(U_{t+1} R_{t,t+1}^K - F(U_{t+1})\right)\right]$

5. $R_{t-1,t}^K = F'(U_t)$

6. $\bar{K}_t = \frac{(1-\delta)}{\gamma}\bar{K}_{t-1} + \eta_t^i \left(1 - \Phi\left(\frac{\gamma I_t}{I_{t-1}}\right)\right) I_t$

7. $K_t = U_t \frac{\bar{K}_{t-1}}{\gamma}$

8. $E_t \sum_{t+k}^{\infty} \left[\left(\bar{\beta}\zeta_w\gamma\right)^k \frac{\lambda_{t+k}}{\lambda_t} H_{t+k} \left(\mathfrak{M}_{t,t+k}^w W_t^* - \left(1 + \eta_{t+k}^w\right)\left(C_{t+k} - \frac{\iota_c}{\gamma} C_{t+k-1}\right) H_{t+k}^{\sigma_h}\right)\right] = 0$

9. $W_t^{\frac{1}{\eta_t^w}} = (1-\zeta_w)\left(W_t^*\right)^{\frac{1}{\eta_t^w}} + \zeta_w \left(\frac{\Pi^{1-\iota_w}\Pi_{t-2,t-1}^{\iota_w}}{\Pi_{t-1,t}}\right)^{\frac{1}{\eta_t^w}} W_{t-1}^{\frac{1}{\eta_t^w}}$

10. $Y_t = \eta_t^a K_t^\alpha \left(H_t\right)^{1-\alpha}$

11. $MC_t = \alpha^\alpha (1-\alpha)^{-(1-\alpha)} W_t^{1-\alpha} \left(R_{t-1,t}^K\right)^\alpha \left(\eta_t^a\right)^{-1}$

12. $K_t = \frac{\alpha}{1-\alpha} \frac{W_t}{R_{t-1,t}^K} H_t$

13. $E_t \sum_{k=0}^{\infty} \left(\bar{\beta}\zeta_p\gamma\right)^k \frac{\hat{\lambda}_{t+k}^1}{\hat{\lambda}_t^1} \hat{Y}_{t+k} \left\{\left(\mathfrak{M}_{t,t+k}^p p_t^* - \left(1 + \eta_{t+k}^p\right) MC_{t+k}\right)\right\} = 0$

14. $1 = (1-\zeta_p)(p_t^*)^{\frac{1}{\eta_t^p}} + \zeta_p \left(\frac{\Pi^{1-\iota_p}\Pi_{t-2,t-1}^{\iota_p}}{\Pi_{t-1,t}}\right)^{\frac{1}{\eta_t^p}}$

15. $Y_t = C_t + I_t + F(U_t)\frac{\bar{K}_{t-1}}{\gamma} + gY\eta_t^g$

16. $\frac{R_{t,t+1}}{R} = \left(\frac{R_{t-1,t}}{R}\right)^{\iota_r} \left(\left(\frac{\Pi_{t-1,t}}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^f}\right)^{\phi_y}\right)^{1-\iota_r} \left(\frac{Y_t/Y_{t-1}}{Y_t^f/Y_{t-1}^f}\right)^{\phi_{\Delta y}} \eta_t^r$

<u>*Flex-Price Economy:*</u>

17. $\lambda_t^f = \left(C_t^f - \frac{\iota_c}{\gamma} C_{t-1}^f\right)^{-\sigma_c} \exp\left\{\frac{\sigma_c - 1}{1+\sigma_h}\left(H_t^f\right)^{1+\sigma_h}\right\}$

18. $\lambda_t^f = \bar{\beta}\eta_t^b R_{t,t+1}^f E_t\left[\lambda_{t+1}^f\right]$

19. $1 = Q_t^f \eta_t^i \left(1 - \Phi\left(\frac{\gamma I_t^f}{I_{t-1}^f}\right) - \Phi'\left(\frac{\gamma I_t^f}{I_{t-1}^f}\right)\left(\frac{\gamma I_t^f}{I_{t-1}^f}\right)\right) + \bar{\beta} E_t\left[\frac{\lambda_{t+1}^f}{\lambda_t^f}\eta_{t+1}^i Q_t^f \Phi'\left(\frac{\gamma I_{t+1}^f}{I_t^f}\right)\left(\frac{\gamma I_{t+1}^f}{I_t^f}\right)^2\right]$

20. $Q_t^f = \bar{\beta} E_t\left[Q_{t+1}^f(1-\delta) + \frac{\lambda_{t+1}^f}{\lambda_t^f}\left(U_{t+1}^f R_{t,t+1}^{K,f} - F\left(U_{t+1}^f\right)\right)\right]$

21. $R_{t-1,t}^{K,f} = F'\left(U_t^f\right)$

22. $\bar{K}_t^f = \frac{(1-\delta)}{\gamma}\bar{K}_{t-1}^f + \eta_t^i\left(1 - \Phi\left(\frac{\gamma I_t^f}{I_{t-1}^f}\right)\right) I_t^f$

23. $K_t^f = U_t^f \frac{\bar{K}_{t-1}^f}{\gamma}$

24. $W_t^f = (1+\eta^w)\left(C_t^f - \frac{\iota_c}{\gamma} C_{t-1}^f\right)\left(H_t^f\right)^{\sigma_g}$

25. $Y_t^f = \eta_t^a \left(K_t^f\right)^{\alpha}\left(H_t^f\right)^{1-\alpha}$

26. $MC_t^f = \alpha^{\alpha}(1-\alpha)^{-(1-\alpha)}\left(W_t^f\right) 1 - \alpha\left(R_{t-1,t}^{K,f}\right)^{\alpha}(\eta_t^a)^{-1}$

27. $K_t^f = \frac{\alpha}{1-\alpha}\frac{W_t^f}{R_{t-1,t}^{K,f}} H_t^f$

28. $1 = (1+\eta_t^p)\, MC_t^f$

29. $Y_t^f = C_t^f + I_t^f + F\left(U_t^f\right)\frac{\bar{K}_{t-1}^f}{\gamma} + gY\eta_t^g$

2.C Steady State

From 14.

$$p^* = 1 \tag{SS1}$$

From 13.

$$MC = (1 + \eta^p)^{-1} \tag{SS2}$$

From 2.

$$R = \frac{\Pi}{\bar{\beta}} \tag{SS3}$$

In steady state $\rightarrow \Phi(\cdot) = \Phi'(\cdot) = 0$, from 3.

$$Q = 1 \tag{SS4}$$

From (7):

$$U = 1 \tag{SS5}$$

In steady state $\rightarrow F(\cdot) = 0$, from 4. and 5.

$$R^K = \frac{1}{\bar{\beta}} - (1-\delta) = F'(\cdot) \tag{SS6}$$

From 11.

$$W = \left(MC\alpha^{\alpha}(1-\alpha)^{1-\alpha}\left(R^K\right)^{-\alpha}\right)^{\frac{1}{1-\alpha}} \tag{SS7}$$

From 9.

$$W^* = W \tag{SS8}$$

From 6.

$$\frac{I}{\bar{K}} = 1 - \frac{(1-\delta)}{\gamma} \tag{SS9}$$

From 6. and 7.

$$\frac{I}{K} = \gamma - (1 - \delta) \tag{SS10}$$

From 12.

$$\frac{H}{K} = \frac{1 - \alpha}{\alpha} \frac{R^K}{W} \tag{SS11}$$

From 10.

$$\frac{K}{Y} = \left(\frac{H}{K}\right)^{\alpha - 1} \tag{SS12}$$

Using (SS10) and (SS11)

$$\frac{I}{Y} = \frac{I}{K}\frac{K}{Y} = (\gamma - (1 - \delta)) \left(\frac{H}{K}\right)^{\alpha - 1} \tag{SS13}$$

From 15.

$$\frac{C}{Y} = (1 - g) - \frac{I}{Y} \tag{SS14}$$

From 8.

$$W = (1 - \eta^w)\, C \left(1 - \frac{\iota_c}{\gamma}\right) H^{\sigma_h}$$

$\implies$

$$H^{1+\sigma_h} = \frac{W}{(1 + \eta^w)C} \left(1 - \frac{\iota_c}{\gamma}\right)^{-1}$$

Using (SS11)

$$H^{1+\sigma_h} = \frac{(1 - \alpha)}{\alpha} \frac{R^K K}{(1 + \eta^w)C} \left(1 - \frac{\iota_c}{\gamma}\right)^{-1}$$

Using (SS12) and (SS14)

$$H = \left(\frac{(1 - \alpha)}{\alpha} \frac{R^K}{(1 + \eta^w)} \frac{Y}{C} \frac{K}{Y} \left(1 - \frac{\iota_c}{\gamma}\right)^{-1}\right)^{\frac{1}{1+\sigma_h}} \tag{SS15}$$

With H, it is straight forward to solve for the remaining steady state values of other endogenous variables.

2.D Linearised System

<u>*Sticky-Price Economy:*</u>

1. $C_t = \frac{\frac{\iota_c}{\gamma}}{1+\frac{\iota_c}{\gamma}} C_{t-1} + \frac{1}{1+\frac{\iota_c}{\gamma}} E_t C_{t+1} + \frac{\left(1-\frac{\iota_c}{\gamma}\right)(\sigma_c-1)H^{1+\sigma_h}}{\sigma_c\left(1+\frac{\iota_c}{\gamma}\right)}\left(H_t - E_t H_{t+1}\right)$
$-\frac{1-\frac{\iota_c}{\gamma}}{\sigma_c\left(1+\frac{\iota_c}{\gamma}\right)} E_t\left[R_{t,t+1} - \Pi_{t,t+1}\right] + \eta_t^b$

2. $I_t = \frac{1}{\Phi''\gamma^2\left(1+\bar{\beta}\gamma\right)} Q_t + \frac{1}{1+\bar{\beta}\gamma} I_{t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t I_{t+1} + \eta_t^i$

3. $Q_t = \bar{\beta} R^K E_t R^K_{t,t+1} + \bar{\beta}(1-\delta) E_t Q_{t+1} - \left(R_{t,t+1} - E_t \Pi_{t,t+1} + \eta_t^b\right)$

4. $R^K_{t-1,t} = \frac{F''}{F'} U_t = \frac{\chi}{1-\chi} U_t$

5. $\bar{K}_t = \frac{(1-\delta)}{\gamma} \bar{K}_{t-1} + \frac{I}{\bar{K}}\left(I_t + \gamma^2 \Phi'' \eta_t^i\right)$

6. $W_t = \frac{W_{t-1}}{1+\bar{\beta}\gamma} + \frac{\iota_w \Pi_{t-2,t-1}}{1+\bar{\beta}\gamma} + \frac{(1-\bar{\beta}\zeta_w\gamma)(1-\zeta_w)}{\zeta_w(1+\bar{\beta}\gamma)}\left(\frac{C_t}{1-\frac{\iota_c}{\gamma}} - \frac{\iota_c/\gamma C_{t-1}}{1-\frac{\iota_c}{\gamma}} + \sigma_h H_t - W_t\right) + \eta_t^w$
$-\frac{(1+\bar{\beta}\iota_w\gamma)}{1+\bar{\beta}\gamma}\Pi_{t-1,t} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t \Pi_{t,t+1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t W_{t+1}$

7. $Y_t = \eta_t^a + \alpha K_t + (1-\alpha) H_t$

8. $MC_t = (1-\alpha) W_t + \alpha R^K_{t-1,t} - \eta_t^a$

9. $K_t = W_t - R^K_{t-1,t} + H_t$

10. $\Pi_{t-1,t} = \frac{(1-\bar{\beta}\zeta_p\gamma)(1-\zeta_p)}{\zeta_p(1+\iota_p\bar{\beta}\gamma)} MC_t + \frac{\iota_p}{1-\iota_p\bar{\beta}\gamma}\Pi_{t-2,t-1} + \frac{\bar{\beta}\gamma}{1+\iota_p\bar{\beta}\gamma} E_t \Pi_{t,t+1} + \eta_t^p$

11. $Y_t = \frac{C}{Y} C_t + \frac{I}{Y} I_t + F' \frac{\bar{K}}{Y\gamma} U_t + \eta_t^g$

12. $R_{t,t+1} = \iota_r R_{t-1,t} + (1-\iota_r)\left(\phi_\pi \Pi_{t-1,t} + \phi_y\left(Y_t - Y_t^f\right)\right) + \phi_{\Delta_y}\left(Y_t - Y_{t-1} - Y_t^f + Y_{t-1}^f\right) +$
η_t^m

<u>*Flex-Price Economy:*</u>

17. $C_t^f = \frac{\frac{\iota_c}{\gamma}}{1+\frac{\iota_c}{\gamma}} C^f_{t-1} + \frac{1}{1+\frac{\iota_c}{\gamma}} E_t C^f_{t+1} + \frac{\left(1-\frac{\iota_c}{\gamma}\right)(\sigma_c-1)H^{1+\sigma_h}}{\sigma_c\left(1+\frac{\iota_c}{\gamma}\right)}\left(H_t^f - E_t H^f_{t+1}\right) - \frac{1-\frac{\iota_c}{\gamma}}{\sigma_c\left(1+\frac{\iota_c}{\gamma}\right)} R^f_{t,t+1} + \eta_t^b$

18. $I_t^f = \frac{1}{\Phi''\gamma^2\left(1+\bar{\beta}\gamma\right)} Q_t^f + \frac{1}{1+\bar{\beta}\gamma} I^f_{t-1} + \frac{\bar{\beta}\gamma}{1+\bar{\beta}\gamma} E_t I^f_{t+1} + \eta_t^i$

19. $Q_t^f = \bar{\beta} R^K E_t R_{t,t+1}^{K,f} + \bar{\beta}(1-\delta) E_t Q_{t+1}^f - \left(R_{t,t+1}^f + \eta_t^b \right)$

20. $R_{t-1,t}^{K,f} = \frac{\chi}{1-\chi} U_t^f$

21. $\bar{K}_t^f = \frac{(1-\delta)}{\gamma} \bar{K}_{t-1}^f + \frac{I}{\bar{K}} \left(I_t^f + \gamma^2 \Phi'' \eta_t^i \right)$

22. $K_t^f = U_t^f + \bar{K}_{t-1}^f$

23. $W_t^f = \frac{C_t^f}{1-\frac{\iota_C}{\gamma}} - \frac{\frac{\iota_C}{\gamma}}{1-\frac{\iota_C}{\gamma}} C_{t-1}^f + \sigma_h H_t^f$

24. $Y_t^f = \eta_t^a + \alpha K_t^f + (1-\alpha) H_t^f$

25. $MC_t^f = (1-\alpha) W_t^f + \alpha R_{t-1,}^{K,f} - \eta_t^a$

26. $K_t^f = W_t^f - R_{t-1,t}^{K,f} + H_t^f$

27. $0 = MC_t^f$

28. $Y_t^f = \frac{C}{Y} C_t^f + \frac{I}{Y} I_t^f + F' \frac{\bar{K}}{Y\gamma} U_t^f + \eta_t^g$

Chapter 3

Asset Pricing in General Equilibrium: A New-Keynesian Analysis

This chapter consists of work jointly done with Dr Katsuyuki Shibayama. I was responsible for approximately 60% of the work carried out in this chapter.

3.1 Introduction

This paper examines the ability of the industry-standard New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model to jointly explain both macroeconomic and financial data.

In recent years, the development of DSGE models have undergone considerable progress (Tovar, 2008). In particular, the most recent crop of New Keynesian DSGE models have proved particularly useful in providing a coherent framework from which to examine matters pertaining to monetary policy analysis (Galí and Gertler, 2007; Christiano et al., 2010). Unsurprisingly, New-Keynesian models have gained considerable popularity in both academic and Central banking circles alike. Such support for the DSGE paradigm has been bolstered by advances in computing power and relevant statistical methods now allowing researchers to take these models to data[1]. But, as is typical in the majority of analyses, empirical validation of DSGE models is usually judged on their ability to explain macroeconomic dynamics. A case in point is the celebrated Smets and Wouters (2007) model which has been shown to explain and forecast selected macroeconomic time series to a similar standard to that of a Bayesian vector autoregression (BVAR). By contrast, the ability of DSGE models to match key features of asset prices has been relatively less successful in comparison. As discussed by Cochrane and Piazzesi (2005), the inadequacy of these models to explain both macroeconomic and financial data may be an indication of model misspecification. For if we are confident that the shocks typically identified in DSGE models correspond to the real risks that economic agents face, then it follows that explaining macroeconomic dynamics and explaining asset prices are two sides of the same coin. This is because it is through asset markets in which consumption and investment are allocated through time and different states of nature.

Understanding the symbiotic relationship between macroeconomic and financial variables also has important practical implications. For example, policy makers have been acutely sensitive to the decline in asset prices and their subsequent impact on the macroeconomy following the recent financial crisis. As such, policy makers addressing macro-finance phenomena will undoubtedly require a coherent framework capable of accurately capturing macro-finance interactions.

Our paper is related to those analyses investigating the implications for both business cycle and asset price facts within a general equilibrium framework. Specifically, this model employs the consumption-based capital asset pricing pricing model (C-CAPM) developed independently by Lucas (1978) and Breeden (1979), such that asset prices are determined by the covariation between their respective payoffs and the marginal consumption utility of investors.

Among the asset pricing anomalies to emerge from the general equilibrium paradigm, the

[1]See Herbst and Schorfheide (2015) for an overview on the Bayesian estimation of DSGE models.

equity premium puzzle highlighted by Mehra and Prescott (1985) has received the most attention. Danthine et al. (1992) and Rouwenhorst (1995) find that when the pricing kernel is endogenously determined, it is difficult to achieve sufficient equity premia within a production economy. Their reasoning is that the standard neoclassical economy permits agents to freely divert resources to production thus enabling agents to minimise consumption fluctuations. Increasing the level of risk aversion serves only to strengthen the desire to smooth consumption, resulting in smaller consumption volatility and thus smaller equity premia. Jermann (1998) finds that by incorporating both capital adjustment costs and a consumption habit into an otherwise standard neoclassical economy, his model is able to produce a level of equity premium much closer to that found in the data. Intuitively, the two frictions generate greater risk premia since, working in tandem, they imply that agents not only care greatly about consumption volatility, but they are also inhibited in their ability to offset variable consumption streams via production[2].

In addition to the equity premium puzzle, the asset pricing literature has also stressed the difficulty of replicating certain features of interest rate data. Indeed, several studies have noted the inability of the earlier generation of DSGE models to replicate both the sign and quantity of term premia found in the data (Backus et al., 1989; Donaldson et al., 1990; Den Haan, 1995; Chapman, 1997) - the so called "bond premium puzzle". For the New Keynesian paradigm, this is particularly unsettling, since bond prices largely reflect expectations of future policy decisions which are in turn influenced by expected inflation and output deviations. Given the use of New Keynesian modelling in guiding the setting of monetary policy, the ability of these models to generate accurate bond yield moments may serve as a useful metric to evaluate their empirical performance.

In an important contribution, Swanson and Rudebusch (2012) offer a solution to the bond premium puzzle by augmenting the prototypical New Keynesian model with Epstein-Zin preferences and long-run inflation risk. In pricing financial claims, Epstein-Zin preferences

[2] Boldrin et al. (2001) also reach similar conclusions.

are particularly attractive in that they allow the level of risk aversion to be calibrated independently of the investor's elasticity of intertemporal substitution. This is essential to ensuring that higher levels of risk aversion affect only risk premiums in their model without significantly impacting the fit of macroeconomic moments. Also important is the addition of long-run inflation risk, which is used as a device to raise the variability of inflation which in turn engenders larger fluctuations in the price of the long-term nominal bond. As such, higher levels of long-run inflation risk will prompt Epstein-Zin investors to demand greater levels of risk premia for holding nominal bonds[3]. While the findings of Swanson and Rudebusch (2012) are promising, it remains to be seen whether their results extend to the more empirically realistic DSGE models typically employed by Central banks. Moreover, it is of interest to examine the extent to which these models are able to explain a wider array of assets in addition to the nominal term structure. We therefore differentiate our analysis from Swanson and Rudebusch (2012) by using the industry-standard Smets and Wouters (2007) model to examine its ability to replicate both standard business cycle statistics in addition to matching moments on equities and real, nominal and corporate bonds by use of a non-linear solution method.

Our paper is also similar to De Graeve (2008) in that our analysis uses a medium-scale DSGE model in order to derive a model-consistent description of the credit spread. Our novelty, however, stems from use of the external finance premium in the corporate bond Euler equation, so that entire corporate term structure can be priced in a manner consistent with the C-CAPM methodology. Moreover, our analysis is differentiated by use of a non-linear solution method so that the role of uncertainty and its impact on the credit spread can be studied.

The remainder of this paper is structured as follows. Section 3.2 describes the model economy used in our analysis and sets out the optimisation problems faced by its agents. Section

[3]In an earlier contribution, Piazzesi et al. (2006) also document how the use of Epstein-Zin preferences may be used to manufacture a large and positive term premium. However, since their analysis is restricted to an endowment economy, the contribution of Swanson and Rudebusch (2012) is distinguished by the fact they are able to solve the bond premium puzzle within a production economy.

3.3 provides details on the solution method used to solve our model and how it gives rise to risk premia for financial assets. Section 3.4 presents the main results of the paper by comparing our model-implied moments against US data. Furthermore, we provide intuition behind our results by varying the weight on key model features so that we can examine their marginal effects on risk premia. Section 3.5 contains our concluding comments.

3.2 Model

The benchmark model used in our analysis augments the Smets and Wouters (2007) model with several key additions found to be successful in matching bond moments. For example, we follow Swanson and Rudebusch (2012) and permit a role for Epstein and Zin (1989) and Weil (1990) preferences. Furthermore we include a time-varying inflation target as in Gürkaynak et al. (2005) to introduce a source of long-run nominal risk into our model. One other key addition in our analysis is that we also incorporate the financial accelerator mechanism of Bernanke et al. (1999) by following the formulation presented in Christensen and Dib (2008). Full details of the model's equilibrium conditions are left to the Appendix.

3.2.1 Households

A representative household, indexed over i $\in$ [0,1], is assumed to maximise an instantaneous utility function, U_t, which is non-separable in consumption, C_t and labour supply, H_t. Formally:

$$U_{i,t}\left(C_{i,t}, H_{i,t}\right) = \zeta_t^b \frac{\left(C_{i,t} - \gamma_c C_{t-1}\right)^{1-\sigma_c}}{1-\sigma_c} \exp\left\{\frac{\sigma_c - 1}{1+\sigma_h} H_{i,t}^{1+\sigma_h}\right\} \tag{3.1}$$

where ζ_t^b is representative of a preference shock. The household receives utility from the consumption good relative to an external habit, the strength of which is dictated by γ_c and receives disutility from the supply of labour services, H_t. The parameters governing the inverse of the inter-temporal elasticity of substitution and the elasticity of labour supply are given by σ_c and σ_h respectively. We assume that $U\left(C, H\right)$ is increasing in its first argument, decreasing in its second, twice differentiable and strictly concave. We incorporate Epstein and Zin preferences into our analysis by following the formulation specified in Swanson and Rudebusch (2012). Specifically we assume that the household's value function is given by[4]:

$$V_{i,t} = \begin{cases} U_{i,t} + \beta \left(E_t \left[V_{i,t+1}^{1-\varrho} \right] \right)^{\frac{1}{1-\varrho}} & \text{for } U_{i,t} \geq 0 \qquad (3.2a) \\ U_{i,t} - \beta \left(E_t \left[(-V_{i,t+1})^{1-\varrho} \right] \right)^{\frac{1}{1-\varrho}} & \text{for } U_{i,t} \leq 0 \qquad (3.2b) \end{cases}$$

where $\beta \in (0,1)$ is the household's subjective discount factor and ϱ governs the degree of household risk aversion[5]. The preference structure presented in (3.2) defines preferences recursively as a function of current utility, $U_{i,t}$, and a certainty equivalent of future utility, $E_t\left[V_{t+1}\right]$. Crucially, as discussed by Swanson and Rudebusch (2012), (3.2) nests the special case of expected utility preferences when $\varrho = 0$. Each household is constrained with respect to their period budget constraint:

$$C_t + \frac{D_t}{R_{t,t+1}^N P_t} + \sum_{j=1}^{m} \frac{\mathfrak{P}_{j,t}^N B_{j,t}^N}{P_t} + \sum_{j=1}^{m} \frac{\mathfrak{P}_{j,t}^C B_{j,t}^C}{P_t} + \sum_{j=1}^{m} \mathfrak{P}_{j,t}^R B_{j,t}^R + \frac{\mathfrak{P}_t^E \Omega_t}{P_t}$$

$$= W_t H_t + \frac{D_{t-1}}{P_t} + \sum_{j=1}^{m} \frac{\mathfrak{P}_{j-1,t}^N B_{j,t-1}^N}{P_t} + \sum_{j=1}^{m} \frac{\mathfrak{P}_{j-1,t}^C B_{j,t-1}^C}{P_t} + \sum_{j=1}^{m} \mathfrak{P}_{j-1,t}^R B_{j,t-1}^R + \frac{\left(\mathfrak{P}_t^E + \mathfrak{D}_t\right) \Omega_{t-1}}{P_t} - T_t \tag{3.3}$$

where D_t denotes nominal deposits held by the financial intermediary which, by assumption, pay the return on government bonds, $R_{t,t+1}^N$. Holdings of j-period nominal Government, nominal corporate and real Government bonds are denoted by $B_{j,t}^N$, $B_{j,t}^C$ and $B_{j,t}^R$ respectively, their respective prices are given by $\mathfrak{P}_{j,t}^N$, $\mathfrak{P}_{j,t}^C$ and $\mathfrak{P}_{j,t}^R$. Households also own and invest in

[4]As discussed in Epstein and Zin (1989), this assumption is necessary to avoid complex numbers.

[5]The exact functional form for ϱ is given by:

$$\varrho = 1 - \frac{1 - \sigma_\gamma}{1 - \sigma_c}$$

where σ_γ governs the level of risk aversion. Since $\sigma_c > 1$ and assuming $\sigma_\gamma > \sigma_c$, higher values of σ_γ correspond to higher levels of risk aversion. These conditions imply that ϱ is decreasing in the level of risk aversion.

shares of the wholesale firm[6], the price and quantity of which are given by $\mathfrak{P}_t^E$ and Ω_t respectively. Furthermore, households also receive a dividend, $\mathfrak{D}_t$, from holding equities. Household labour is supplied at the real wage, W_t, and T_t denotes a lump-sum tax levied by the Government. The solution to the household's problem is defined as the maximised value of (3.2) subject to the budget constraint (3.3)[7].

3.2.2 Wage Setting

We assume the existence of a labour packer that aggregates differentiated household labour to form an index of labour input to used by the entrepreneur. Labour is aggregated in accordance with a Dixit-Stiglitz agreggator:

$$H_t = \left(\int_0^1 H_{i,t}^{\frac{\varepsilon_w - 1}{\varepsilon_w}} \, di \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \tag{3.4}$$

where ε_w denotes the elasticity of substitution among household labour. Maximisation of the labour packer's problem yields the familiar demand function:

$$H_{i,t} = \left(\frac{W_{i,t}}{W_t} \right)^{-\varepsilon_w} H_t \tag{3.5}$$

Staggered wage setting is introduced à la Calvo (1983) so that each period each household faces a constant probability, $\theta_w \in [0,1]$, of being unable to re-optimise their wage rate. For those households unable to re-optimise, we assume the following indexation rule:

$$W_{i,t+k} = \prod_{n=1}^{k} \frac{\mathfrak{G} \left(\Pi_{t,t+n}^{\dagger} \right)^{1-\iota_w} \Pi_{t-1,t-1+n}^{\iota_w}}{\Pi_{t,t+n}} W_{i,t} \tag{3.6}$$

[6]The optimisation problem of the wholesale firm will be introduced later on.

[7]As discussed by Swanson (2017), the assumptions imposed on $U(C_{i,t}, H_{i,t})$ above in addition to the conditions imposed under (3.2) guarantee the existence of a unique optimal choice for (C_t, H_t) at each point in time given the realisation of state variables.

where $\Pi_{t-1,t} = \frac{P_t}{P_{t-1}}$ denotes nominal price inflation, $\Pi^{\dagger}_{t,t+1}$ denotes a time-varying inflation target set by the Central bank and $\iota_w \in [0,1]$ controls the strength of indexation. For the remaining fraction of households able to re-optimise their wage, $W_{i,t}$, do so by solving the following optimisation problem subject to the demand constraint (3.5):

$$\max_{W_{i,t}} E_t \sum_{k=0}^{\infty} \left\{ (\beta\theta_w)^k \frac{\lambda_{t+k}}{\lambda_t} \left(\begin{array}{c} \zeta^w_{t+k}\zeta^b_{t+k}\frac{(C_{t+k}-\gamma_c C_{t+k-1})^{1-\sigma_c}}{1-\sigma_c} \exp\left\{\frac{\sigma_c-1}{1+\sigma_h} H^{1+\sigma_h}_{i,t+k}\right\} \\ +\lambda_{t+k} \prod_{n=1}^{k} \frac{\mathfrak{G}\left(\Pi^{\dagger}_{t,t+n}\right)^{1-\iota_w} \Pi^{\iota_w}_{t-1,t-1+n}}{\Pi_{t,t+n}} W_{i,t} H_{i,t+k} \end{array} \right) \right\}$$

where λ_{t+k} is representative of the household's marginal utility of consumption and ζ^w_t denotes a wage mark-up shock assumed to follow an ARMA(1,1) process.

3.2.3 Investment Good Producer (IGP)

The IGP uses a fraction of the final good, I_t, purchased from the retail firm to produce the efficient investment good, $\bar{I}_t$, in accordance with the following technology:

$$\bar{I}_t = \zeta^i_t \left(1 - \Phi\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \tag{3.7}$$

where ζ^i_t denotes a shock to the marginal efficiency of investment and $\Phi(\cdot)$ is an investment adjustment cost function assumed to follow the formulation adopted by Christiano et al. (2005)[8]. At the end of the each period the IGP sells the efficient investment good to the entrepreneur at price Q_t, implying the following maximisation problem:

$$\max_{I_t} E_t \sum_{k=0}^{\infty} \beta^k \frac{\lambda_{t+k}}{\lambda_t} \left(Q_{t+k}\zeta^i_{t+k}\left(1 - \Phi\left(\frac{I_{t+k}}{I_{t+k-1}}\right)\right) I_{t+k} - I_{t+k}\right) \tag{3.8}$$

[8] $\Phi = \Phi' = 0$ and $\Phi'' > 0$

3.2.4 Entrepreneur

Entrepreneurs hire labour and capital services to produce the intermediate good, $Y_{j,t}$, in accordance with Cobb-Douglas technology:

$$Y_{j,t} = \zeta_t^a \left(Z_{j,t} K_{j,t-1}\right)^{\alpha} \left(\mathfrak{G}^t H_{j,t}\right)^{1-\alpha} \tag{3.9}$$

where ζ_t^a denotes a neutral TFP shock, Z_t denotes capacity utilisation, K_t represents capital services and $\mathfrak{G}$ is representative of labour-augmenting technical progress. At the end of each period, entrepreneurs purchase the investment good through a combination of net worth, N_t, and external finance (provided by a financial intermediary) to subsequently accumulate capital via the capital law of motion.

$$K_t = \left(1 - \delta\left[Z_t\right]\right) K_{t-1} + \zeta_t^i \left(1 - \Phi\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \tag{3.10}$$

Following Greenwood et al. (1988) we introduce the depreciation function[9] to capture the notion that higher utilisation rates lead to faster depreciation of the capital stock. Crucially, as Bernanke et al. (1999) show, the external financing cost will be priced at a spread over the risk-free rate. The magnitude of this spread, the external finance premium (EFP), is a decreasing function in the quantity of collateralised net worth as demonstrated in the equation below.

$$R^L_{t,t+1} = F\left(\cdot\right) R^N_{t,t+1} \tag{3.11}$$

where the loan rate charged by the financial intermediary is denoted by $R^L_{t,t+1}$ and function F denotes the external finance premium which is modelled as:

$$F\left(\cdot\right) = \left(\frac{Q_t K_t}{N_t} \frac{N}{K}\right)^{\psi} \tag{3.12}$$

[9] $0 \geq \delta \leq 1$, $\delta' > 0, \delta'' > 0$

where ψ captures the elasticity of the EFP to changes in the financial health of the entrepreneur. Implicit in (3.11) is an asymmetry of information problem in which the bank cannot observe the productivity of the entrepreneur without incurring a cost. If the entrepreneur defaults on their loan, then the bank must pay a cost to audit the loan and recover the outcome of the investment. A decrease in net worth, for example, increases the entrepreneur's incentive to misreport the outcome of the project translating into a riskier loan book for the bank. Anticipating higher defaults and higher auditing costs, the bank will now charge a higher loan rate because it still has to ensure that it is able to pay the risk-free rate on household deposits.

The objective of the entrepreneur is to maximise their book value. For assets, the entrepreneur holds undepreciated capital valued at price Q_t, plus the income received from the production of output which it sells at cost, MC_t. Liabilities include the costs associated with the loan contract in addition to the cost of renting labour services. Formally, the entrepreneur's maximisation problem is presented below.

$$\max_{K_t, Z_t, H_t} E_t \sum_{t+k}^{\infty} \left\{ \varphi^k \begin{pmatrix} MC_{t+k} Y_{i,t+k} + Q_{t+k} \left(1 - \delta \left[Z_{t+k}\right]\right) K_{t+k-1} \\ -\frac{R^L_{t+k-1,t+k}}{\Pi_{t+k-1,t+k}} \left(Q_{t+k-1} K_{t+k-1} - N_{t+k-1}\right) - W_{t+k} H_{t+k} \end{pmatrix} \right\}$$

As in Bernanke et al. (1999), $\varphi \in [0, 1]$ denotes the survival probability of entrepreneurs. The assumption that entrepreneurs have a finite life is to ensure that entrepreneurial net worth never becomes so large that external finance is not required. The law of motion for entrepreneurial net worth is given by the equation below.

$$N_t = \varphi \left(R^K_{t-1,t} Q_{t-1} K_{t-1} - \frac{R^L_{t-1,t}}{\Pi_{t-1,t}} \left(Q_{t-1} K_{t-1} - N_{t-1}\right) \right) + (1 - \varphi) \mathfrak{N}_t \tag{3.13}$$

So that net worth in the current period will equal the current gross return on capital (purchased in the previous period), $R^K_{t-1,t}$, minus the contractual rate (agreed in the previous period) multiplied by the quantity borrowed. For those entrepreneurs exiting the economy, it is assumed that they transfer their resources to newly entering entrepreneurs in the form of seed money denoted by $\mathfrak{N}_t$.

3.2.5 Retailer

The output of the retailer is packaged from a continuum of goods produced by wholesalers, $Y_{i,t}$, in accordance with a CES aggregator:

$$Y_t = \left(\int_0^1 Y_{i,t}^{\frac{\varepsilon_p - 1}{\varepsilon_p}} \, di \right)^{\frac{\varepsilon_p}{\varepsilon_p - 1}} \tag{3.14}$$

where ε_p denotes the elasticity of substitution among wholesaler output. Retailers, operating in perfectly competitive markets, seek to maximise profits subject to the technology constraint in (3.14). The solution to the retailer's problem yields the familiar demand function below.

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon_p} Y_t \tag{3.15}$$

3.2.6 Wholesaler

To facilitate aggregation, we assume that the wholesaler purchases output from the entrepreneur at cost, and subsequently differentiates the entrepreneur's output without cost. Furthermore, wholesalers sell their output in a monopolistically competitive market subject to a Calvo (1983) constraint. For those wholesalers unable to re-optimise their price we assume the following indexation rule:

$$p_{i,t+k} = \prod_{n=1}^{k} \frac{\left(\Pi^{\dagger}_{t,t+n} \right)^{1-\iota_p} \Pi^{\iota_p}_{t-1,t-1+n}}{\Pi_{t,t+n}} p_{i,t} \tag{3.16}$$

Those wholesalers able to re-optimise will pick a price consistent with maximising the following optimisation problem subject to the demand constraint in (3.15) after adjusting for indexation:

$$\max_{p_{i,t}} E_t \sum_{k=0}^{\infty} (\beta\theta_p)^k \frac{\lambda_{t+k}}{\lambda_t} \left\{ \left(\prod_{n=1}^{k} \frac{\left(\Pi^{\dagger}_{t,t+n}\right)^{1-\iota_p} \Pi^{\iota_p}_{t-1,t-1+n}}{\Pi_{t,t+n}} p_{i,t} - \zeta^p_{t+k} MC_{t+k} \right) Y_{i,t+k} \right\} \tag{3.17}$$

where ζ^p_t denotes a price mark-up shock that also follows an ARMA(1,1) process.

3.2.7 Government

Monetary policy is conducted through a Taylor-type rule which sees the Central bank respond positively to inflation and output.

$$\frac{R_{t,t+1}}{R} = \left(\frac{R_{t-1,t}}{R}\right)^{\iota_r} \left(\left(\frac{\Pi_{t-1,t}}{\Pi^{\dagger}_{t-1,t}}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}} / \mathfrak{G}\right)^{\phi_y} \right)^{1-\iota_r} \zeta^r_t \tag{3.18}$$

Under this set-up, the Central bank attempts to minimise deviations between actual and target inflation, $\Pi^{\dagger}_{t-1,t}$. Following the formulation presented in Gürkaynak et al. (2005) the law of motion for $\Pi^{\dagger}_{t-1,t}$ is presented below.

$$\Pi^{\dagger}_{t-1,t} = (1 - \rho_\pi)\, \Pi^{\dagger} + \rho_\pi \Pi^{\dagger}_{t-2,t-1} + \epsilon \left(\Pi_{t-2,t-1} - \Pi^{\dagger}_{t-2,t-1}\right) \tag{3.19}$$

If $\epsilon > 0$, then, consistent with the empirical evidence presented by Gürkaynak et al (2005), long-term inflation expectations will respond to developments in current inflation and output. Furthermore ζ^r_t denotes a monetary policy shock.

Fiscal policy in our model constitutes exogenous government spending shocks which, in contrast to Smets and Wouters (2007), do not respond to developments in TFP.

3.2.8 Asset Pricing

In pricing the assets under consideration, we exploit the recursive nature of the fundamental asset pricing equation central to the C-CAPM framework. For example, assuming no arbitrage, the Euler equation used to price real bonds is given by:

$$\mathfrak{P}^R_{t,j} = E_t\left[\Lambda_{t,t+1}\mathfrak{P}^R_{t+1,j-1}\right] \tag{3.20}$$

Following common convention we assume that upon maturity each real bond will pay one unit of consumption. Exploiting the recursive nature of (3.20) we can price the entire real term structure by chaining the stochastic discount factor:

$$\begin{bmatrix} \mathfrak{P}^R_{t,1} \\ \mathfrak{P}^R_{t,2} \\ \vdots \\ \mathfrak{P}^R_{t,40} \end{bmatrix} = \begin{bmatrix} \Lambda_{t,t+1}\cdot 1 \\ \Lambda_{t,t+1}\cdot \mathfrak{P}^R_{t+1,1} \\ \vdots \\ \Lambda_{t,t+1}\cdot \mathfrak{P}^R_{t+1,39} \end{bmatrix} = \begin{bmatrix} e^{-1\cdot\mathfrak{Y}^R_{t,1}} \\ e^{-2\cdot\mathfrak{Y}^R_{t,2}} \\ \vdots \\ e^{-40\cdot\mathfrak{Y}^R_{t,40}} \end{bmatrix} \tag{3.21}$$

The nominal term structure can be recovered in exactly the same manner after making an adjustment for inflation in the respective stochastic discount factor:

$$\mathfrak{P}^N_{t,j} = E_t\left[\frac{\Lambda_{t,t+1}}{\Pi_{t,t+1}}\mathfrak{P}^N_{t+1,j-1}\right] \tag{3.22}$$

We then define the term spread as the difference between the 40 quarter and 1 quarter nominal spot rates:

$$TS_t = \mathfrak{Y}^N_{t,40} - \mathfrak{Y}^N_{t,1} \tag{3.23}$$

The Bernanke et al. (1999) framework provides a natural way to capture the risk of investing in corporate bonds relative to those of the Government. To price corporate bonds we therefore adjust the Euler equation to capture the notion of credit risk via the EFP:

$$\mathfrak{P}^C_{t,j} = E_t\left[\frac{\Lambda_{t,t+1}}{F\left(\frac{Q_tK_t}{N_t}\frac{N}{K}\right)^{\psi}\Pi_{t,t+1}}\mathfrak{P}^C_{t+1,j-1}\right] \tag{3.24}$$

Our measure for the corporate bond spread is:

$$CS_t = \mathfrak{Y}^C_{t,40} - \mathfrak{Y}^N_{t,40} \tag{3.25}$$

For equities, we assume that the profits of the wholesale firm are paid out as dividends to the household[10]. Dividends are therefore equal to the difference between the wholesale firm's expenditure and revenue:

$$\mathfrak{D}_t = Y_t - MC_t \tag{3.26}$$

Therefore, the current price of an equity is given by:

$$\mathfrak{P}^E_t = E_t \left[\Lambda_{t,t+1} \left(\mathfrak{P}^E_{t+1} + \mathfrak{D}_{t+1} \right) \right] \tag{3.27}$$

where the household's stochastic discount factor, $\Lambda_{t,t+1}$, is used to discount future payoffs as it is the household who is the owner of shares in this model. The return on equity is then given by:

$$R^E_{t,t+1} = \frac{\mathfrak{P}^E_{t+1} + \mathfrak{D}_{t+1}}{\mathfrak{P}^E_t} \tag{3.28}$$

Consequently, the equity premium can then be computed by subtracting the one period real bond return from the return on holding equities:

$$EP_t = R^E_{t,t+1} - \mathfrak{Y}^R_{t,1} \tag{3.29}$$

3.3 Model Solution

The objective of this paper is to examine how the macroeconomy influences asset prices in the presence of uncertainty. Such analyses are only meaningful by use of non-linear solution techniques so that the joint roles of risk and uncertainty can be properly evaluated. Lin-

[10]This formulation is essentially the same as in De Paoli et al. (2010).

earised models and the techniques used in their solution impose the certainty equivalence principle implying that risk premia is restricted to zero. To permit a role for uncertainty, we turn to the perturbation literature and solve our model numerically around the deterministic steady state using the second-order approximation routines available in DYNARE[11]. The deterministic steady state being that point the economy will settle in the absence of exogenous shocks and in which agents do not take into account the possibility of future shocks when formulating their economic plans. In what follows, we provide a general overview of the solution method paying particular attention into how uncertainty shifts the prices of assets and gives rise to risk premia.

Our model may be represented by the stochastic vector function, F, which contains the equilibrium conditions of the model economy.

$$E_t F\left(c_{t+1}, c_t, s_{t+1}, s_t\right) = 0 \tag{3.30}$$

Where c_t is an n_c x 1 vector containing the model's control variables, s_t is a n_s x 1 vector containing the state variables such that the total variables, n, is equal to $n = n_c + n_s$. Furthermore, s_t can be partitioned into the model's endogenous and exogenous state variables respectively $s_t = [s_t^1 \ s_t^2]'$. The assumption that all exogenous shocks follow AR(1) processes implies that the vector s_t^2 will evolve according to:

$$s_{t+1}^2 = \Lambda s_t^2 + \hat{\eta}\sigma\varepsilon_{t+1} \tag{3.31}$$

where $\hat{\eta}$ is an n_{s_2} x n_{s_2} covariance matrix, σ denotes the perturbation parameter, ε_t is the n_{s_1} x 1 vector of innovations assumed to be iid with zero mean and covariance matrix I. The solution we seek to (3.30) is of the form:

$$c_t = \hat{g}(s_t, \sigma) \tag{3.32}$$

[11]See Adjemian et al. (2011)

$$s_{t+1} = \hat{h}(s_t, \sigma) + \eta\sigma\varepsilon_{t+1} \tag{3.33}$$

where $\eta = \left[\underset{n_{s1} \text{ x } n_{s1}}{\emptyset}, \underset{n_{s2} \text{ x } n_{s2}}{\hat{\eta}}\right]'$

A second order approximation of $\hat{g}$ and $\hat{h}$ around the deterministic steady state yields[12]:

$$[g(s_t,\sigma)]^i = [g(\bar{s},0)]^i + [g_s]^i_a[s-\bar{s}]_a + [c_\sigma]^i\sigma + \frac{1}{2}[g_{ss}]^i_{ab}[s-\bar{s}]_a[s-\bar{s}]_b + [g_{s\sigma}]^i_a[s-\bar{s}]_a\sigma + \frac{1}{2}\left([g_{\sigma\sigma}]^i\sigma^2\right) \tag{3.34}$$

and

$$[h(s_t,\sigma)]^j = [h(\bar{c},0)]^j + [h_s]^j_a[s-\bar{s}]_a + [s_\sigma]^j\sigma + \frac{1}{2}[h_{ss}]^j_{ab}[s-\bar{s}]_a[s-\bar{s}]_b + [h_{s\sigma}]^j_a[s-\bar{s}]_a\sigma + \frac{1}{2}\left([h_{\sigma\sigma}]^j\sigma^2\right) \tag{3.35}$$

where $i = 1, ..., n_c$, $a, b = 1, ..., n_s$ and $j = 1, ..., n_s$

As discussed by Schmitt-Grohé and Uribe (2004) to ensure a unique solution to (3.30) we must have $g_\sigma = h_\sigma = 0$ that is, to a first-order, the certainty-equivalence principle must hold[13]. At a second-order approximation, however, the uncertainty in the economy shifts the constants of the policy functions via correction terms[14] to define the stochastic steady state. Therefore in the stochastic steady state agents now take into account the possibility of future shocks so that the correction terms are correcting for precautionary savings and engendering risk premia for financial assets.

[12]The notation borrows heavily from Schmitt-Grohé and Uribe (2004). For example the n_c x n_s matrix, $[c_s]$, containing the first-order derivatives $[c_s]^i_a$ denotes the element corresponding to the intersection of the i^{th} row and a^{th} column. For the n_c x n_s x n_s three-dimensional array containing the second-order derivatives $[c_s s]^i_{ab}$ corresponds to the intersection of the i^{th} row ,a^{th} column and the b^{th} layer.

[13]This condition must also hold for the cross derivatives i.e. $g_{s\sigma} = h_{s\sigma} = 0$. Intuitively, this implies that, at a second-order approximation, the coefficients in the policy rules that are linear in the state vector are independent of the covariance matrix of ε_t.

[14]From (3.34) and (3.35), the respective correction terms for g and h are given by $g_{\sigma\sigma}$ and $h_{\sigma\sigma}$.

3.4 Results

In this section, we examine the ability of our model to match the moments of US financial and macroeconomic data. We first present results for our full model and subsequently shut down key parameters to pin down the impact of various model features on macroeconomic and financial moments.

3.4.1 Model Parametrisation and Data Description

To conduct our simulations we calibrate our model using parameters that are typical of those found in tantamount studies, the values of which are reported in Table 3.1. For example, we calibrate that subset of parameters typically associated with medium-scale models to the mean of the posterior distribution estimated in Smets and Wouters (2007)[15]. Similarly, we calibrate our exogenous processes to match the estimates obtained by these authours. Following Christensen and Dib (2008) we calibrate ψ to 0.042 and set the deterministic steady state EFP to 1.0075 which corresponds to an annual corporate bond spread of 3%. Furthermore, we set the steady state level of leverage[16] to 2. Consistent with the estimate obtained by De Graeve (2008), we fix the probability of entrepreneurial survival, φ, to 0.9858. The degree to which changes in recent inflation are transmitted through to the inflation target, ϵ, is fixed to 0.02 consistent with the findings presented in Gürkaynak et al. (2005). Related, we set the inflation reaction coefficient, ϕ_π, to 1.5 which is slightly lower than the value reported in Smets and Wouters (2007)[17].

A key value to calibrate in our analysis is the Epstein-Zin parameter, ϱ, which dictates the degree of risk aversion. Since the equilibrium conditions of our model are identical to the case of expected utility, estimating a non-linear DSGE model is required to identify the

[15] One exception is that we calibrate the consumption habit, γ_c, to the slightly higher value of 0.81. This is to achieve a better fit for our model when matching macroeconomic moments.

[16] Defined as the ratio of capital to net worth.

[17] Our Taylor-rule, however, differs to that of Smets and Wouters (2007)) in two ways. First, we assume the Central bank attempts to minimise the gap between current and target inflation. Secondly, we assume the Central bank responds to deviations in output from its previous value as opposed to its flex-price analogue.

higher-order effects that are crucial for risk premia that Epstein and Zin preferences introduce. Consequently, there are few studies to provide estimates of the Epstein-Zin parameter since, as discussed by Van Binsbergen et al. (2012), estimating non-linear DSGE models is computationally challenging, forcing the researcher to make a compromise between theoretical detail and empirical relevance. For example, Andreasen (2012) estimates a third-order approximation of a simple DSGE model on both macro and interest rate data and obtains a value of -183. Swanson and Rudebusch (2012) also consider a simple DSGE model but opt for a different estimation strategy by using grid search. Conditional on their model hitting 100 basis points of term premia, Swanson and Rudebusch (2012) report a range of -148 for ϱ. Paries and Loublier (2010) consider a medium scale model and find that in order to match historical estimates of term premia their model requires a value of -930 for ϱ. Our calibration strategy loosely follows Paries and Loublier (2010) in that we set ϱ to -525[18] in order to hit a term spread of 143 basis points[19].

In order to assess the empirical validity of our model, we compare simulated moments from our model against US data. Output, Y, is measured as real GDP available at the Bureau of Economic Analysis (BEA). To construct our consumption series, C, we take personal consumption expenditures from the BEA and deflate it by the GDP deflator, also available from the BEA. Similarly, for investment, I, we take fixed private investment from the BEA and deflate it by the GDP deflator. Hours, H, is defined as total hours in the non-farm business sector and can be accessed via the Bureau of Labor Statistics (BLS). The real wage series, W, is constructed by deflating hourly compensation in the non-farm business sector which is also available at the BLS. We take the natural log of Y,C, I, H and W and then take the first-difference of each series to compute the standard deviation relative to that of output. Our data for these series is quarterly and spans from 1960:1 - 2007:1. For inflation, Π, we take the change in the quarterly GDP price index expressed at an annual rate from

[18] Since it is difficult to estimate this parameter directly, our calibration strategy implies that we are picking a value for ϱ in order to fit the data as opposed to explaining the data which would require us to estimate ϱ directly.

[19] Since this is the historical average for the term spread computed over our sample.

the BEA. Our policy rate, R^N, is constructed using the end-of-month federal funds rate from the Federal Reserve Board expressed at an annual rate. We construct our term spread series, $\mathfrak{Y}_{40}^N - R^N$, by subtracting the 3-month Treasury bill rate from the 10-year Treasury bond rate. Each series can be accessed from the Federal Reserve Board and Gürkaynak et al. (2007) respectively. We follow Swanson and Rudebusch (2012) who opt for using the raw series of Π, R^N and $\mathfrak{Y}_{40}^N - \mathfrak{Y}_1^N$ to compute standard deviations as opposed to using filtered series. For the credit spread, $\mathfrak{Y}_{40}^C - \mathfrak{Y}_{40}^N$, we take Moody's Baa corporate bond yield relative to the yield on the 10-Year Treasury expressed at an annual rate. Since the market for sub-investment grade bonds prior to the 1980s was not particularly well developed (Gertler and Lown, 1999), our data series for the credit spread reflects this and spans the slightly shorter period of 1986:1 - 2007:1. Moments for the real risk-free rate, $\mathfrak{Y}_1^R$, and the real return on equities, R^E, are taken directly from Nezafat and Slavik (2009)[20] who compute the respective means and standard deviations for these series using US quarterly data spanning 1964:1 - 2008:4.

3.4.2 Full Model

The results of our full model simulation are reported in the third column of Table 3.2, several results are worth pointing out. First, through calibrating ϱ, our model is not only able to replicate the level of term spread but it also performs adequately in matching its standard deviation. Interestingly, calibrating our model with a bias towards fitting the term spread does not appear to hinder its ability to explain other interest rate series. For instance, our model performs well in matching the moments of the credit spread, albeit slightly over-predicting both the mean and standard deviation. Similarly, the mean and standard deviation computed for the real risk free rate are reasonably close to the values found in the data.

For equities, the mean return implied by our model understates that of the data by 427 basis

[20] Details on the construction of each series are provided in the appendix of Nezafat and Slavik (2009), A.3.

points, indicative of a poor fit in this area. Consequently, we also observe that our benchmark model performs poorly in matching the excess return on equities, $R^E - \mathfrak{Y}_1^R$. Moreover, the standard deviation that we compute for equities is less than 6 times the amount reported in the data, denoting a clear area of discrepancy between our model and the data. From a theoretical perspective, Hördahl et al. (2008) argues that the inability of DSGE models to match equity moments may not represent a source of misspecification. Indeed, these authours suggest that the price of equities are often be driven by factors disconnected from the real economy - information acquisition, bubbles etc. Indeed, Miao et al. (2015) show that in the case of the US, non-fundamentals in the form of bubbles are an important driver in US stock market fluctuations during the post-war period. The pricing of bonds, however, should largely reflect the future path of monetary policy which is arguably more predictable[21] than the future profitability of firms that is crucial for pricing equities. We therefore take confidence in that our model does a reasonable job in matching various bond moments despite performing poorly in its attempt to explain equity moments.

Finally, turning to the macroeconomic series and, perhaps unsurprisingly, our model performs adequately in matching both the relative standard deviation of real aggregates and the standard deviation of inflation and the nominal interest rate.

3.4.3 Expected Utility Preferences

In order to evaluate the role played by Epstein-Zin preferences, we set $\varrho = 0$ so that our benchmark results can be contrasted with those that would pertain under the case of expected utility. The fourth column of Table 3.2 presents the results of this exercise. Our first observation is that the standard deviation of all series is left unaffected under the instance of expected utility preferences. Indeed, Van Binsbergen et al. (2012) show that, to a second-order approximation, the decision rules computed under Epstein-Zin and expected utility

[21] See Blattner et al. (2008) for a recent overview of Central banks and their pursuit for greater transparency and predictability.

preferences differ by only a constant[22]. As such, the impact of using Epstein-Zin preferences will only be realised through analysing the stochastic averages of financial assets, a matter we now turn to. Figures 3.1, 3.2 and 3.3 present the implications for the respective means of the term spread, credit spread and equity premium by varying the Epstein-Zin parameter. From Figure 3.1, both the one quarter and 40 quarter nominal spot rates are increasing with higher levels of risk aversion. The long spot rate, however, increases at a faster rate causing the term spread to increase with higher levels of risk aversion. To provide insight into our results it is instructive to examine the impulse response functions of variables key to the pricing of nominal bonds. Figure 3.4 presents the impulse response functions of the stochastic discount factor (SDF), inflation and the prices of the 40 quarter real and nominal bonds in response to those innovations jointly responsible for the majority of fluctuations in our model: TFP, Government spending and monetary policy shocks. In the interest of brevity, we discuss only the impulses pertaining to the TFP shock, although the other shocks imply similar co-movements for the variables of interest. Through the wealth effect, the decrease in TFP lowers current consumption causing the stochastic discount factor to increase. Furthermore, through its impact on marginal costs, the fall in TFP also implies higher inflation which erodes the real value of the nominal bond's pay-off and therefore causes its price to fall. Since the nominal bond loses value at a time when additional consumption is greatly valued, it is considered risky and therefore rational agents will demand risk premia for holding such bonds. Naturally, the quantity of term premia demanded will be increasing in the level of risk aversion, which is what we observe in Figure 3.1.

Turning to the credit spread and we observe from Figure 3.2 that both the 40 quarter Corporate and Government yields are increasing with higher levels of risk aversion. Since the Government yield increases at a faster rate, this implies that the credit spread is decreasing in the level of risk aversion. Of obvious importance when analysing corporate bonds is the response of the external finance premium, as this determines the spread over the cor-

[22]Consequently, impulse response functions of endogenous variables will be unaffected by varying the Epstein-Zin parameter upto a second-order approximation.

responding Government bond. Focussing on the first column of Figure 3.5 and, in contrast to Bernanke et al. (1999), we observe that the external finance premium actually decreases in response to a negative TFP shock. Responsible, is the fact that our formulation features a contractual rate specified in nominal terms rather than one expressed in real terms as in Bernanke et al. (1999). Our model therefore permits a channel for shifts in unexpected inflation to alter the real debt-burden. To illustrate this point, the second row of Figure 3.5 plots both the contractual rate (specified in real terms) and the gross return to capital. Whilst we observe that both rates fall on impact of the TFP shock, the loan rate falls by relatively more such that the gap between these two rates represents a flow of unexpected profits for the entrepreneur which boosts their net worth and in turn lowers the external finance premium. For the corporate bond, due to higher inflation, we also observe a fall in price implying that corporate bonds are also risky and will therefore command risk premia in a similar manner to Government bonds. However, relative to the Government bond, the fall in the external finance premium implies that the corporate bond retains more value causing the credit spread to be decreasing in the level of risk aversion.

Figure 3.3 reveals that the equity return, risk-free rate and the equity premium are all decreasing in the level of risk aversion. The decline in the risk-free rate is indicative of agents bidding up the price of the risk-free asset through the desire to precautionary save. To provide insight into the behaviour of the equity return, Figure 3.6 plots the responses of the equity value and dividend to a negative monetary policy shock[23]. The cut in interest rates not only boosts the equity value but also increases the level of dividends received by the household. Relative to nominal assets which lose value in a high-inflation state, equities offer security in that both their price and dividend increase. Agents are therefore willing to except a lower return on equities in exchange for the insurance that they provide.

The results in this section demonstrate the appeal of using Epstein-Zin preferences in that they are able to bring our model much closer to matching the moments of financial vari-

[23]Variance decompositions reveal that the monetary policy shock explains the majority of variation in the equity return.

ables without distorting the fit of key macroeconomic series. In this regard, our results are supportive of the similar conclusions reached by Tallarini (2000), Backus et al. (2007) and Swanson and Rudebusch (2012).

3.4.4 Financial Accelerator Effects

In this subsection we assess the importance of the financial accelerator on macro and financial moments by setting $\psi = 0$. The fifth column in Table 3.2 reveals that by switching off financial accelerator effects we observe a clear deterioration in fit for the majority of our macro series, particularly for the nominal series. In this regard, we compliment the literature which has shown that including a credit market friction can improve the fit of macro variables (Christensen and Dib, 2008; De Graeve, 2008; Merola, 2015). Furthermore, our results also suggest that the inclusion of the financial accelerator significantly improves the fit of bond moments.

Focussing first on the implications for nominal Government bond yields, Figure 3.7 reveals that the term spread is increasing as the strength of the financial accelerator is raised, since the 40 quarter nominal spot rate is increasing at a faster rate relative to the 1 quarter nominal spot rate. Similarly, inspection of impulse response functions yields great insight behind our results. Figure 3.10, for example, reports the respective impulse response functions as the strength of the financial accelerator is raised. Focussing once more on those impulses pertaining to the negative TFP shock, we observe that as ψ is increased, there is little impact on the response of the stochastic discount factor. The inflation response, however, does exhibit amplification in light of greater financial accelerator effects. This is because the credit market friction in our model actually decelerates the impact of the negative TFP shock. Recall that a negative shock to TFP effects a fall in the external finance premium which not only limits the initial drop in investment but also serves to support a recovery in both investment and output. Consequently, the fall in aggregate demand is attenuated as we raise the strength of the credit market friction, hence the higher levels of inflation. The

implication for nominal-bond holders is that higher inflation leads to correspondingly larger losses in capital value and thus prompts investors to demand greater levels of risk-premia.
Turning now to corporate bonds, we see observe from Figure 3.8 that the credit spread is decreasing in ψ since the corporate yield increases at a slower rate relative to the Government yield. Figure 3.11 reports the impact on the corporate bond price as the strength of the financial accelerator is increased. It is important to note that as ψ is increased, net worth is raised via a reduction in the real debt burden. We illustrate this point in the first column and first row of Figure 3.11 which plots the gap between the capital return and the contractual rate. As discussed, a positive gap corresponds to a transfer of profits to the entrepreneur which raises their net worth. Furthermore, by raising ψ we also increase the extent to which changes in net worth are transmitted through to the external finance premium[24]. Both effects serve to lower the external finance premium and the corresponding spread over the Government bond. The implication for the corporate bond price is that as we raise ψ the loss of capital value associated with higher inflation is, to a large extent, being offset by falls in the external finance premium. As such, the corporate bond is still perceived as risky since its price decreases, but the loss in value is still smaller relative to the loss in value characterising the Government bond. Consequently, the credit spread is decreasing as the strength of the financial accelerator is increased.

Figure 3.9 reports the implications for the risk free rate, the equity return and the equity premium as the strength of the credit market friction is varied. For the risk-free rate, analysis of Figure 3.10 reveals that, particularly for the Government spending and monetary policy shocks, higher levels of ψ have the effect of amplifying the response of the stochastic discount factor. Of course, greater volatility in the stochastic discount factor is a precursor for precautionary savings which explains why the risk-free rate is decreasing in ψ.
To understand the equity return, we focus on the monetary policy shock and present the responses of the equity value and the dividend for various values of ψ. From Figure 3.12,

[24] See equation (3.11).

The dividend received from holding equities is increasing in ψ. Relative to the nominal assets which lose correspondingly more value when the strength of the financial accelerator is increased, holding equities provides investors with dividend income. As such, investors will therefore accept a lower return on equities as ψ is raised due to the additional insurance provided[25] implying that equities offer an increasingly effective hedge against inflation as we strengthen the effect of the financial accelerator. Investors will therefore accept a lower return on equities as ψ is raised due to the additional insurance provided. Since the risk-free rate decreases at a faster rate relative to the equity return, the equity premium is increasing in the strength of the credit market friction.

3.4.5 Long-Run Inflation Risk

A key finding of Swanson and Rudebusch (2012) is that the inclusion of both long-run risk and Epstein-Zin preferences is crucial to their model's ability to generate sufficient risk premia in nominal bonds. Their results, however, are sensitive to the nature of long-run risk assumed, since each form of risk will imply different implications for the covariance between consumption and inflation. For example, the inclusion of long-run productivity risk in the spirit of Bansal and Yaron (2004) is shown to lower the nominal term premium since it lowers the negative correlation between consumption and inflation in their model. By contrast, the introduction of long-run inflation risk via a time-varying inflation target systematically increases the negative correlation between consumption and inflation thus generating higher term premia. In our paper, the notion of long-run inflation risk constitutes both a time-varying inflation target a la Gürkaynak et al. (2005) and a relatively low inflation reaction coefficient.

We first turn our attention to assessing the significance of long-run inflation risk on the

[25] Although the initial response of dividends is increasing in ψ, we subsequently observe a faster reversion back to steady state for the equity value as ψ in increased. This is indicative of the financial accelerator propagating the monetary policy shock causing the Central bank to tighten policy relatively faster in order to stabilise the economy (see Figure 3.10). Consequently, it is the expectation of higher interest rates which begins to choke off the impact of the initial loosening of policy causing the equity price to tend towards steady state relatively faster.

moments of our macro series. It is clear from Table 3.2 that the inclusion of inflation risk significantly improves the fit of the model-implied inflation and the nominal interest rate series. In the absence of inflation risk, the standard deviations of these nominal variables understate the data by over 1 percentage point. Interestingly, however, we find that on the real side of the economy we observe a slight worsening in fit for the relative standard deviation of the hours and investment series by introducing long-run inflation risk into our model.

Turning to the financial series, Figure 3.13 plots the implications for the term spread as the magnitude of inflation risk is varied. With greater inflation risk, the term spread and the yields on both the 1 and 40 quarter bonds are all increasing. Similar to before, we now provide insight into our results by discussing the impulse responses pertaining to a negative TFP shock. Impulse responses for various levels of inflation risk are reported in Figure 3.16. With $\epsilon > 0$, the Central bank responds to the TFP shock by gradually raising the inflation target. Since agents incorporate the increase in the inflation target when formulating their price and wage setting decisions, the response of inflation is amplified as ϵ is increased. Related, is the simultaneous lowering of the inflation reaction coefficient since it ensures that the Central bank somewhat facilitates the increase in inflation variability by being more passive in its policy stance. As a result, higher inflation risk translates into larger losses of capital value for the nominal bond investor via higher levels of inflation. As such, investors demand a higher quantity of risk premia for holing nominal Government bonds in the face of greater inflation risk.

For the credit spread, Figure 3.14 reveals that as the degree of inflation risk is raised, the yield on the Government bond increases at a faster rate relative to the corporate bond, implying that the credit spread is decreasing with higher levels of inflation risk. From the first column of Figure 3.17, we observe that, similar to the Government bond, the price of the corporate bond falls in the face of higher inflation implied by a negative TFP shock. However, the additional inflation also reduces the real debt burden and provides a boost to the net worth of entrepreneurs. As a result, the fall in the external finance premium attenuates the corporate bond's loss of value and thus provides a structural interpretation of why the credit spread is decreasing as the level of inflation risk is increased.

Finally, we now discuss the impact of long-run inflation risk on the stochastic mean of the equity premium. Figure 3.15 indicates that the risk-free rate is decreasing in the level of inflation risk. As can be seen in Figure 3.16, the volatility of the stochastic discount factor is clearly increasing as the degree of inflation risk is increased. Consequently, agents increase their precautionary savings causing the yield on the risk-free rate to fall in equilibrium. Regarding the equity return, Figure 3.18 plots the responses of the equity price and dividend to an expansionary monetary policy shock. As made clear by the figure, the initial responses of the equity value and dividends are both increasing as the the level of long-run inflation risk is raised. Investors therefore perceive equities as a safe investment as they offer an effective hedge against higher inflation. This explains why both the equity return and the equity premium are both decreasing as we instil greater inflation risk into our model.

3.5 Conclusion

This paper has revisited the ability of the workhorse New Keynesian DSGE model to jointly replicate both macroeconomic and financial moments. Our central result is that by appending the Smets and Wouters (2007) model with Epstein-Zin preferences, a financial accelerator and long-run inflation risk, we are able to successfully match bond yield moments without compromising the fit of key macroeconomic series. In matching the stochastic means of financial assets, our results are particularly dependent on the use of Epstein-Zin preferences in order to generate sufficient risk premia and precautionary savings. Our findings are of particular interest to the bond-pricing literature in that we show how the introduction of Epstein-Zin preferences into an empirically relevant DSGE model offers a flexible approach to yielding sizeable term premia. In this regard, our results may be seen as an extension to the analysis of Swanson and Rudebusch (2012).

This paper has also demonstrated how the inclusion of a financial accelerator can bring these class of models closer to matching both macroeconomic and financial data. While the implications of financial frictions on macroeconomic series are well documented, research has been relatively less active in documenting the ramifications for fitting bond prices by modelling a credit market friction. The contribution of our analysis is to show how a financial friction may be used to generate realistic implications for term premia whilst also leading to improvements in matching the relative standard deviations of macroeconomic aggregates. The principle mechanism behind this result, is that the financial friction systematically increases the covariance between the stochastic discount factor and nominal bond price thus leading investors to demand greater quantities of term premia.

By a similar mechanism, we find long-run inflation risk to also be an important determinant in generating a realistic quantity of term premia, since it also raises the covariance between the pricing kernel and nominal bond price. Moreover, inflation risk is also key in bringing our model closer to matching the standard deviation of inflation and the nominal interest rate. On the real side of the economy, however, we find the inclusion of inflation-risk to be of limited significance in matching the relative standard deviations of those aggregates of interest.

One area in which our model performs particularly poorly, is its inability to match the excessive volatility of stock returns returns found in the data. In light of a growing literature subscribing to the view that non-fundamentals are an important determinant in driving stock price fluctuations, we attribute this result to the assumption that stock prices are explained entirely by market fundamentals in our model.

While this paper has examined the interaction between the economy and asset prices, such interactions have been strictly unidirectional, in that we focus exclusively on how the macroeconomy influences risk premia. Consequently, our analysis is silent about any potential feedback effects from changes in risk premia to the macroeconomy. An interesting avenue for future research could explore how the financial accelerator present in this paper could be extended so that changes in not only macroeconomic conditions but also risk premia are transmitted through to the real economy via fluctuations in the external finance premium.

3.6 Tables

Table 3.1: Baseline Calibration

Parameter	Description	Value	Source
β	Subjective discount factor	0.9984	Smets & Wouters (2007)
Π	Steady state inflation (gross)	1.0078	Smets & Wouters (2007)
$\mathfrak{G}$	Trend growth (gross)	1.0043	Smets & Wouters (2007)
γ_c	Consumption habit	0.81	
σ_c	Inverse of the elasticity of inter-temporal substitution	1.370	Smets & Wouters (2007)
σ_h	Labour elasticity	1.830	Smets & Wouters (2007)
ϱ	Epstein-Zin parameter	-499	
ε_w	Wage elasticity of substitution	10	
ι_w	Wage indexation	0.24	Smets & Wouters (2007)
θ_w	Calvo wage	0.70	Smets & Wouters (2007)
Φ''	Investment adjustment costs	5.74	Smets & Wouters (2007)
α	Capital share	0.19	Smets & Wouters (2007)
F	Steady state EFP	1.0075	Christensen & Dib (2008)
ψ	External finance premium elasticity	0.042	Christensen & Dib (2008)
φ	Entrepreneur survival rate	0.9858	De Graeve (2008)
δ	Capital depreciation rate	0.025	Smets & Wouters (2007)
σ_z	Utilisation adjustment cost	0.54	
ε_p	Price elasticity of substitution	10	
ι_p	Price indexation	0.58	Smets & Wouters (2007)
θ_p	Calvo price	0.66	Smets & Wouters (2007)
g	Govt' share of output	0.18	Smets & Wouters (2007)
ι_r	Taylor rule - smoothing	0.81	Smets & Wouters (2007)
ϕ_π	Taylor rule - inflation	1.5	
ϕ_y	Taylor rule - output	0.08	Smets & Wouters (2007)
ϵ	target inflation	0.02	Gurkaynak et al (2005)
ρ_b	AR(1) preference shock	0.22	Smets & Wouters (2007)
ρ_w	AR(1) wage mark-up shock	0.96	Smets & Wouters (2007)
ρ_i	AR(1) investment shock	0.71	Smets & Wouters (2007)
ρ_a	AR(1) tfp shock	0.95	Smets & Wouters (2007)
ρ_p	AR(1) price mark-up shock	0.89	Smets & Wouters (2007)
ρ_g	AR(1) govt' spending shock	0.97	Smets & Wouters (2007)
ρ_{ag}	AR(1) tfp/govt	0.52	Smets & Wouters (2007)
ρ_m	AR(1) monetary policy shock	0.15	Smets & Wouters (2007)
Θ_w	MA(1) wage mark-up shock	0.84	Smets & Wouters (2007)
Θ_p	MA(1) price mark-up shock	0.69	Smets & Wouters (2007)
σ_b	Std. Dev. preference shock	0.0023	Smets & Wouters (2007)
σ_w	Std. Dev. wage mark-up shock	0.0024	Smets & Wouters (2007)
σ_i	Std. Dev. investment shock	0.0045	Smets & Wouters (2007)
σ_a	Std. Dev. tfp shock	0.0045	Smets & Wouters (2007)
σ_p	Std. Dev. price mark-up shock	0.0014	Smets & Wouters (2007)
σ_g	Std. Dev. govt' spending shock	0.0053	Smets & Wouters (2007)
σ_m	Std. Dev. monetary policy shock	0.0024	Smets & Wouters (2007)

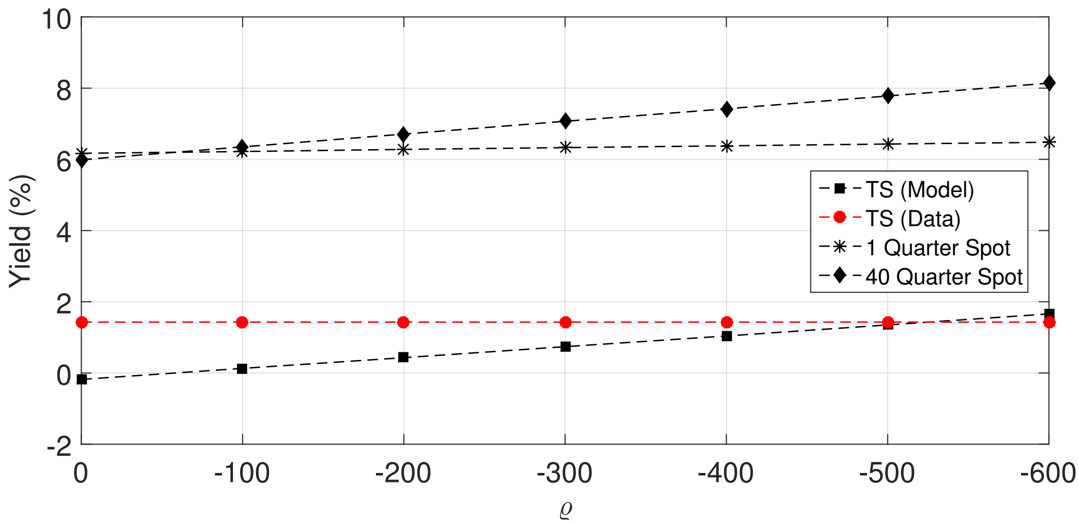
Table 3.2: Model-Implied and Empirical Descriptive Statistics

Unconditional Moment	US Economy	Full Model	EU Pref.	No FA	No LR Inflation Risk
Macro moments					
Rel. S.D. $[C]$	0.80	0.92	0.92	1.20	0.99
Rel. S.D. $[I]$	2.51	3.63	3.63	2.63	3.49
Rel. S.D. $[H]$	0.74	1.01	1.01	0.89	0.81
Rel. S.D. $[W]$	0.67	0.63	0.63	0.78	0.78
S.D. $[\Pi]$	2.52	2.53	2.53	1.55	1.31
S.D. $\left[R^N\right]$	2.71	2.22	2.22	1.49	1.58
Financial moments					
Mean $\left[\mathfrak{Y}_{40}^N - \mathfrak{Y}_1^N\right]$	1.43	1.43	-0.19	0.65	0.16
Std.Dev $\left[\mathfrak{Y}_{40}^N - \mathfrak{Y}_1^N\right]$	1.33	1.77	1.77	1.28	1.41
Mean $\left[\mathfrak{Y}_{40}^C - \mathfrak{Y}_{40}^N\right]$	2.07	2.28	3.15	3.00	2.83
Std.Dev $\left[\mathfrak{Y}_{40}^C - \mathfrak{Y}_{40}^N\right]$	0.50	0.71	0.71	0.00	0.49
Mean $\left[\mathfrak{Y}_1^R\right]$	1.23	1.84	2.86	2.21	2.85
Std.Dev $\left[\mathfrak{Y}_1^R\right]$	2.77	2.58	2.58	2.18	2.01
Mean $\left[R^E\right]$	6.03	1.76	2.90	2.09	3.03
Std.Dev $\left[R^E\right]$	17.6	2.64	2.64	2.21	2.02
Mean $\left[R^E - \mathfrak{Y}_1^R\right]$	4.80	-0.08	0.04	-0.12	0.17

Notes: a. Model-implied moments were obtained by simulating our model for 100,000 replications.
b. See text for details on the construction of each data series.

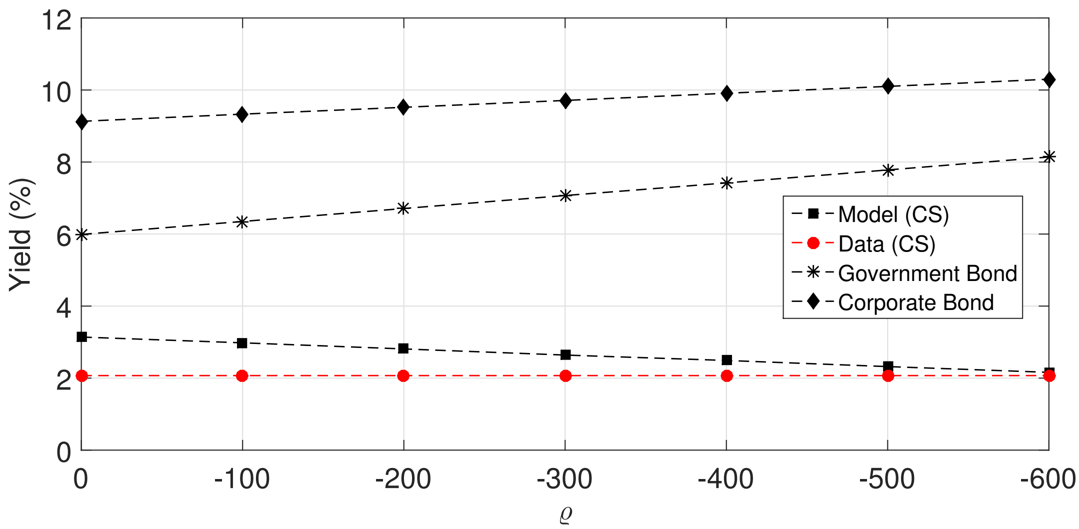
3.7 Figures

Figure 3.1: Mean Nominal Term Premium for Various Levels of Risk Aversion



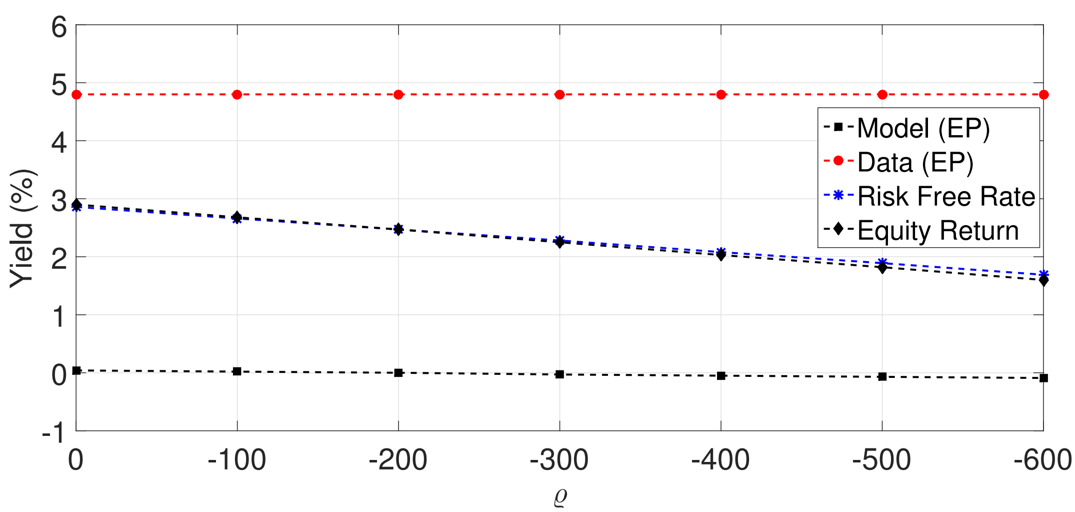
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 1 quarter nominal Government spot rate and the term spread (TS) implied by our model for various levels of risk aversion. All yields are expressed at an annual rate.

Figure 3.2: Mean Credit Spread for Various Levels of Risk Aversion



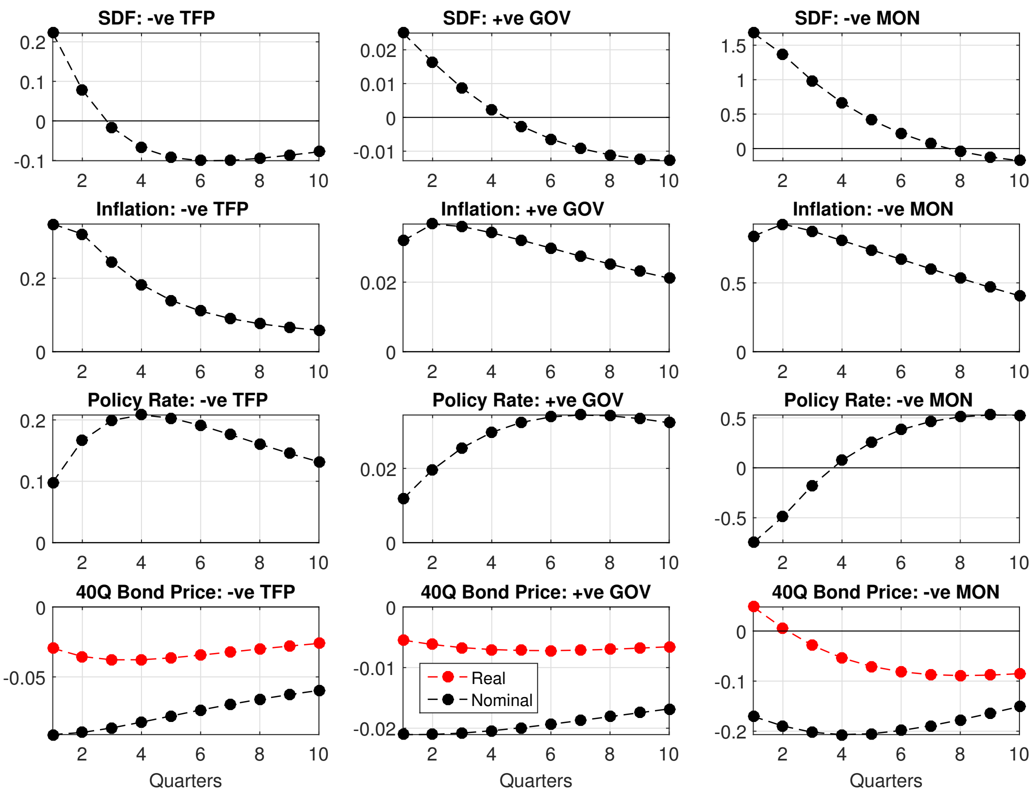
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 40 quarter nominal corporate spot rate and the credit spread (CS) implied by our model for various levels of risk aversion. All yields are expressed at an annual rate.

Figure 3.3: Mean Equity Premium for Various Levels of Risk Aversion



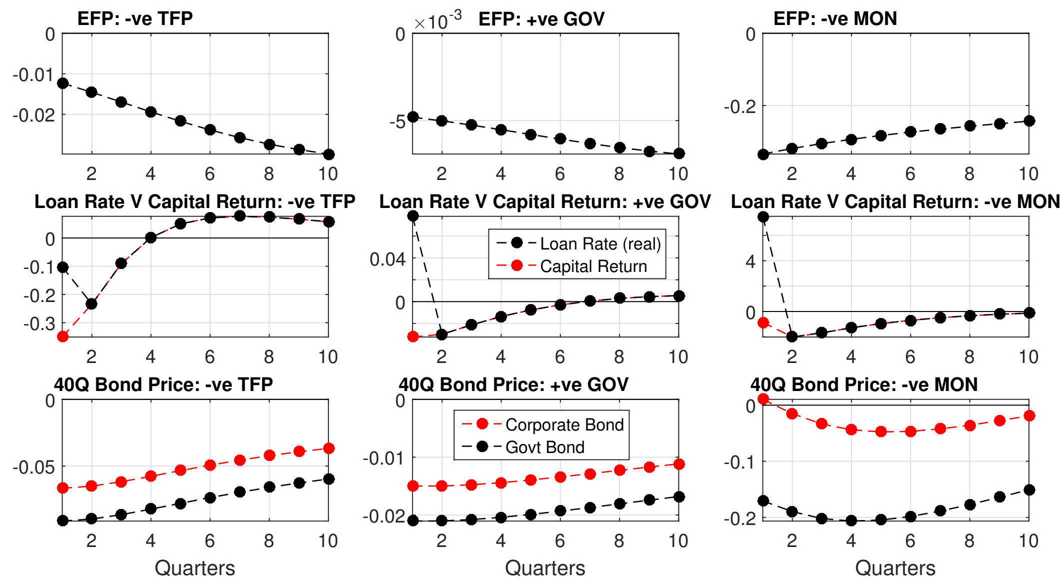
Notes: The figure reports the mean values for the quarterly equity return, quarterly real risk-free rate and the equity premium (EP) implied by our model for various levels of risk aversion. All yields are expressed at an annual rate.

Figure 3.4: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



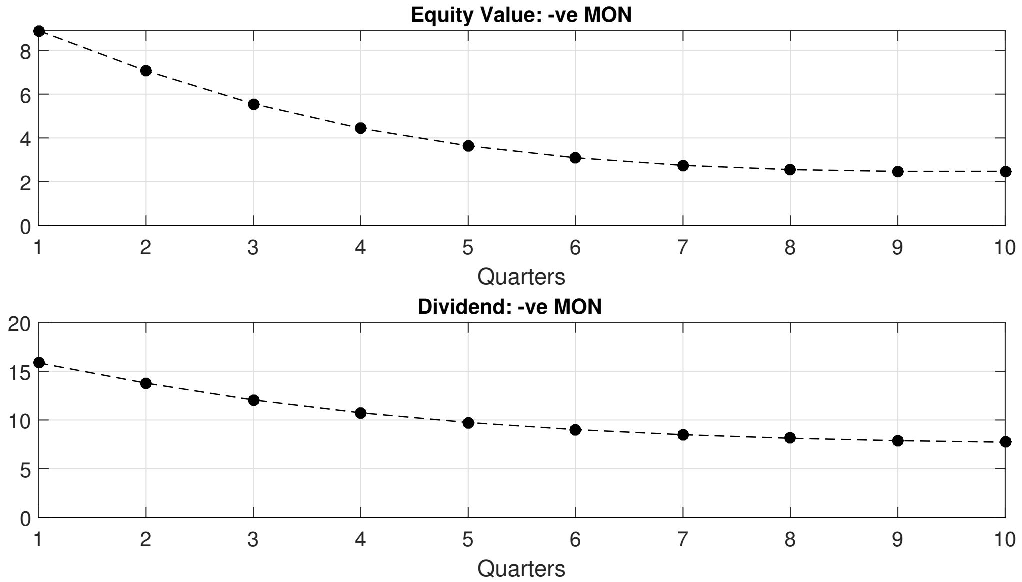
Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.5: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



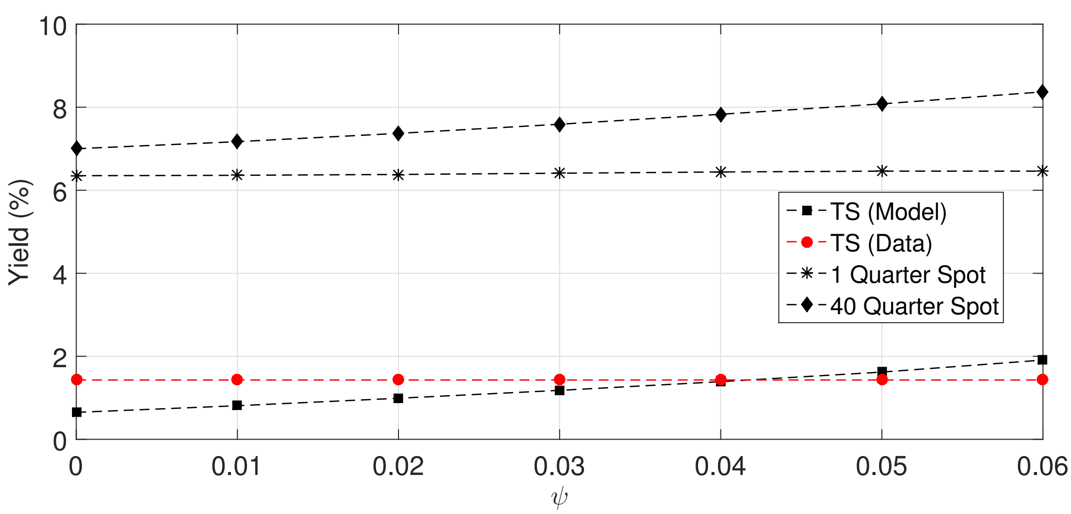
Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.6: Impulse Response Functions: $\zeta_t^r \downarrow$



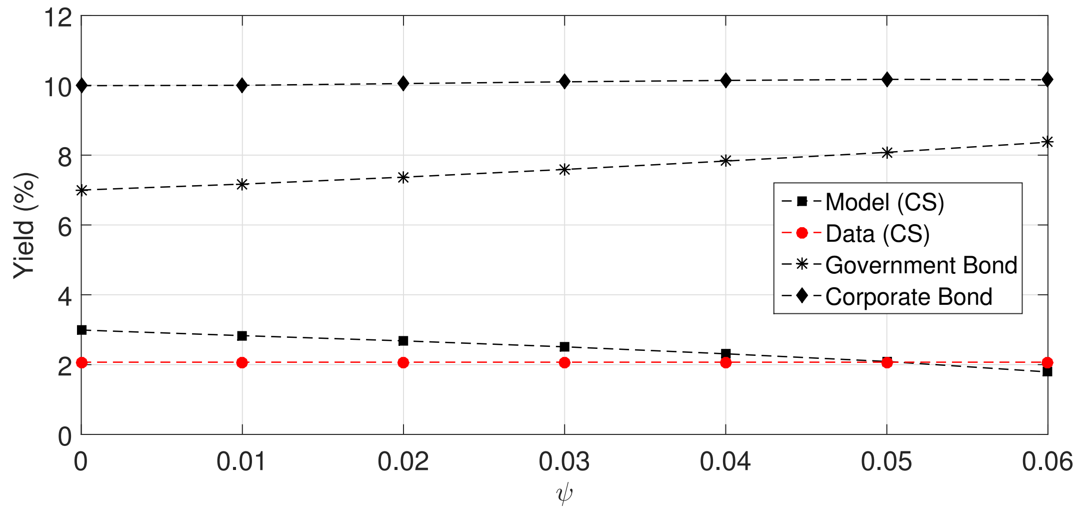
Notes: Presented are impulse response functions to a negative monetary policy shock. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.7: Mean Nominal Term Premium for Various Levels of Financial Accelerator Effects



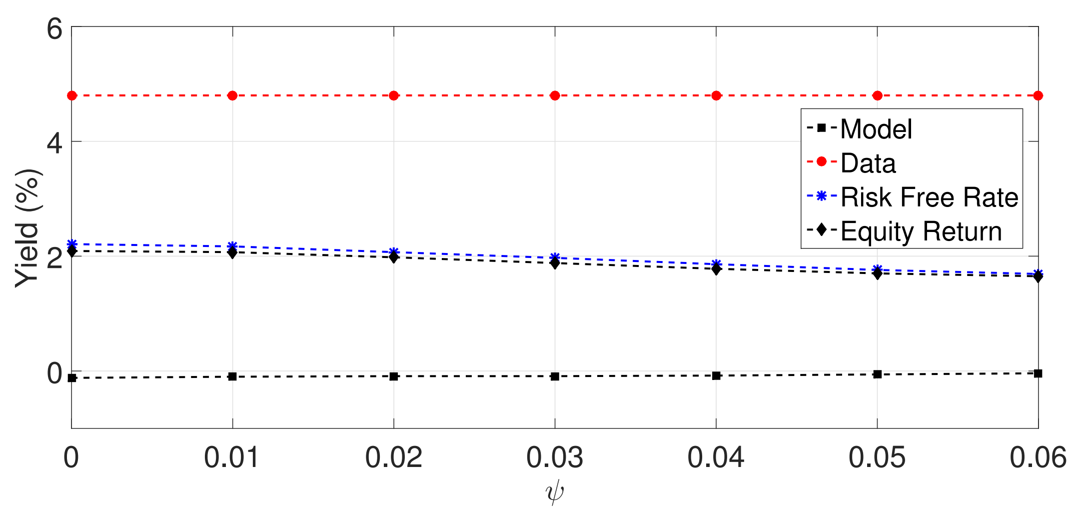
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 1 quarter nominal Government spot rate and the term spread (TS) implied by our model for various levels of financial accelerator effects. All yields are expressed at an annual rate.

Figure 3.8: Mean Nominal Credit Spread for Various Levels of Financial Accelerator Effects



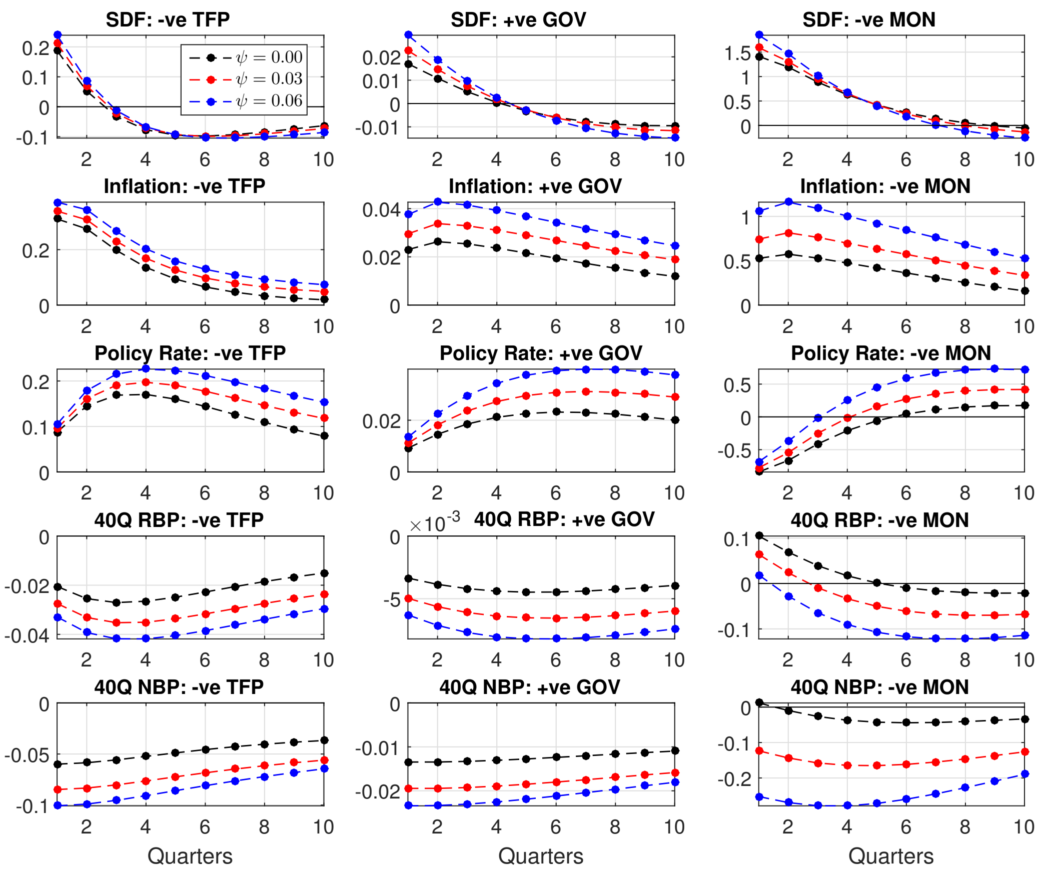
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 40 quarter nominal corporate spot rate and the credit spread (CS) implied by our model for various levels of financial accelerator effects. All yields are expressed at an annual rate.

Figure 3.9: Mean Equity Premium for Various Levels of Financial Accelerator Effects



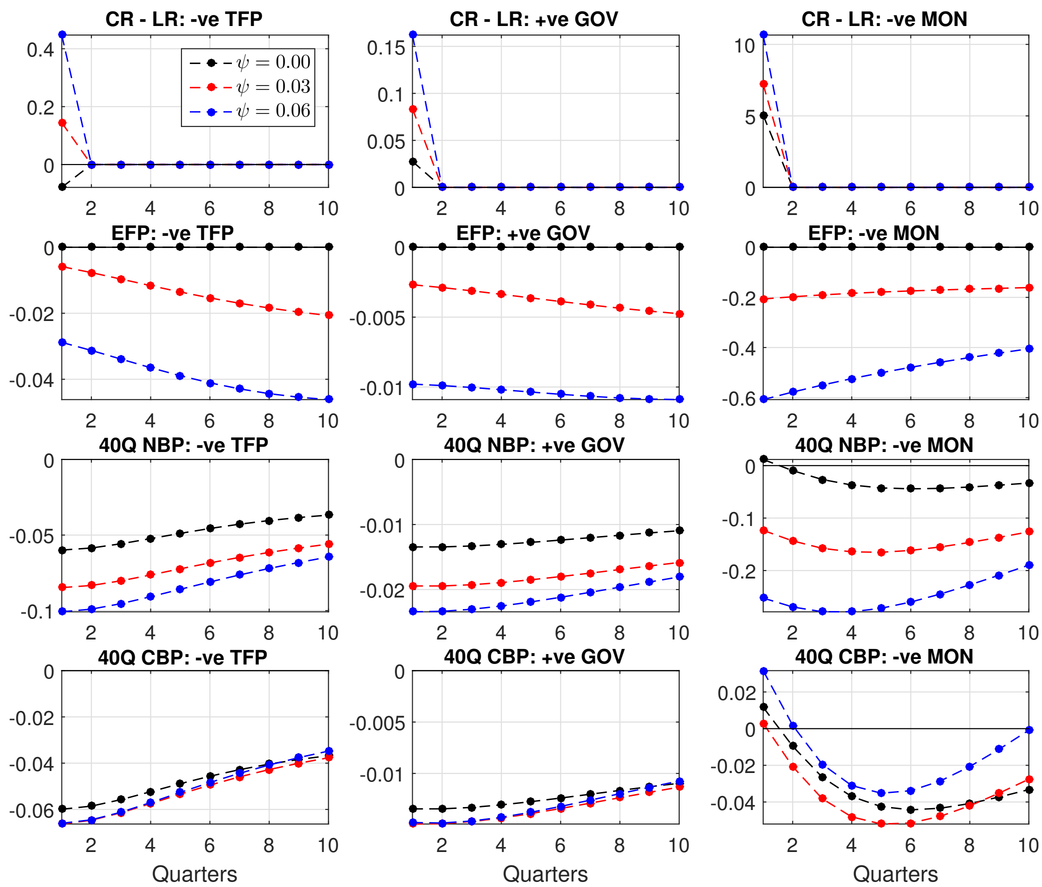
Notes: The figure reports the mean values for the quarterly equity return, quarterly real risk-free rate and the equity premium (EP) implied by our model for various levels of financial accelerator effects. All yields are expressed at an annual rate.

Figure 3.10: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



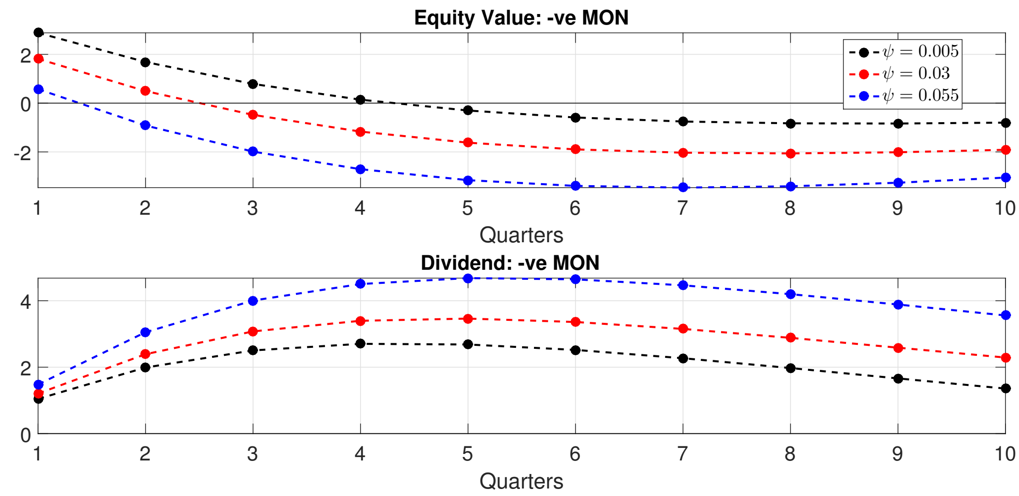
Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.11: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



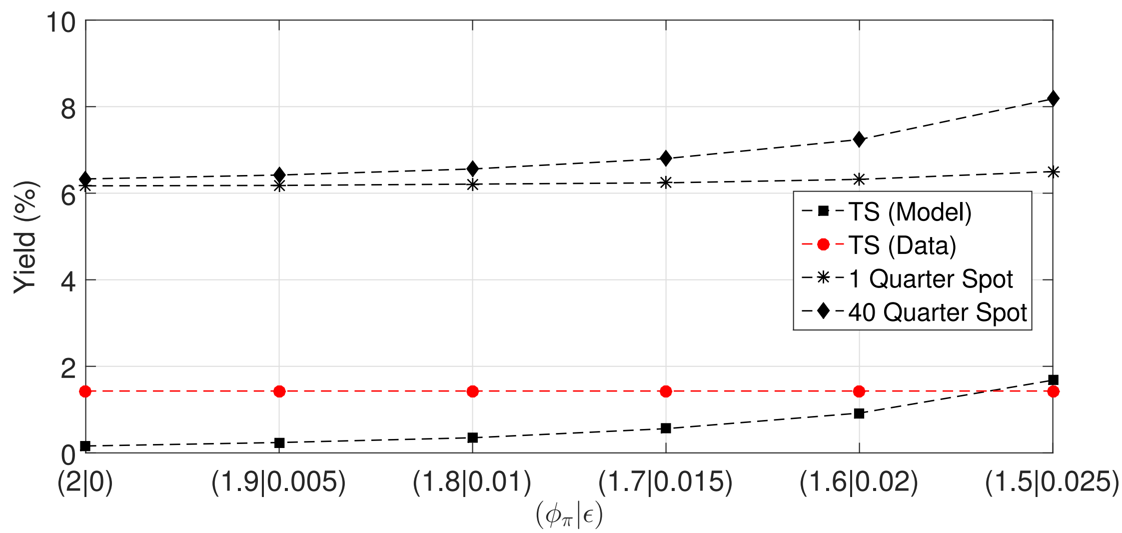
Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.12: Impulse Response Functions: $\zeta_t^r \downarrow$



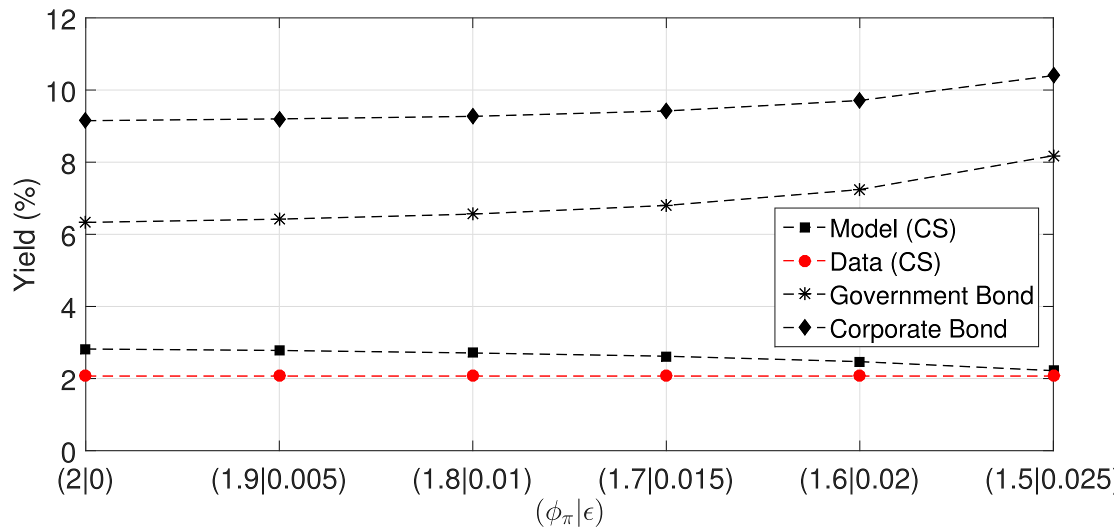
Notes: Presented are impulse response functions to a negative monetary policy shock. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.13: Mean Nominal Term Premium for Various Levels of Long-Run Inflation Risk



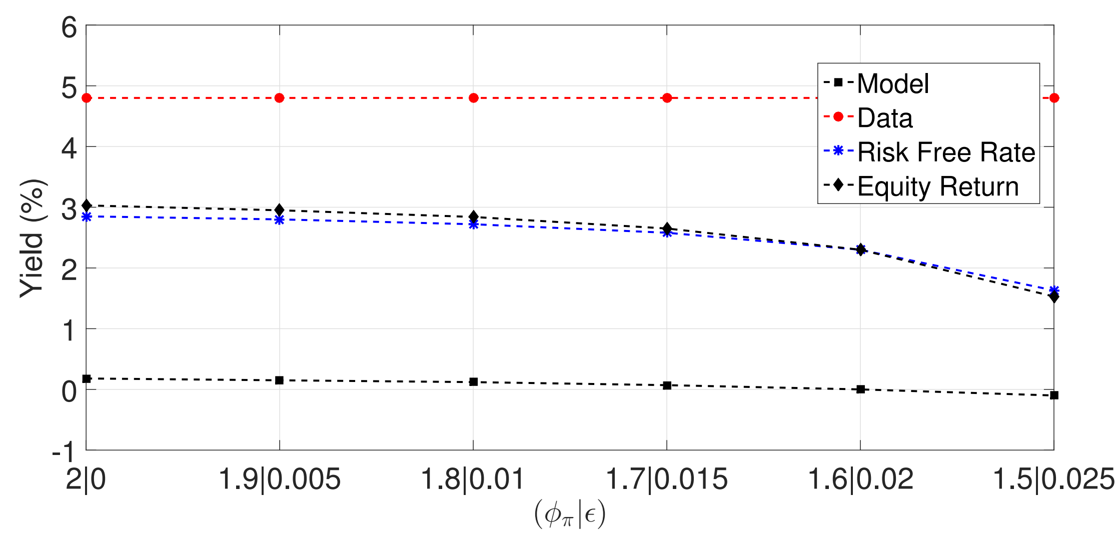
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 1 quarter nominal Government spot rate and the term spread (TS) implied by our model for various levels of long-run inflation risk. All yields are expressed at an annual rate.

Figure 3.14: Mean Nominal Credit Spread for Various Levels of Long-Run Inflation Risk



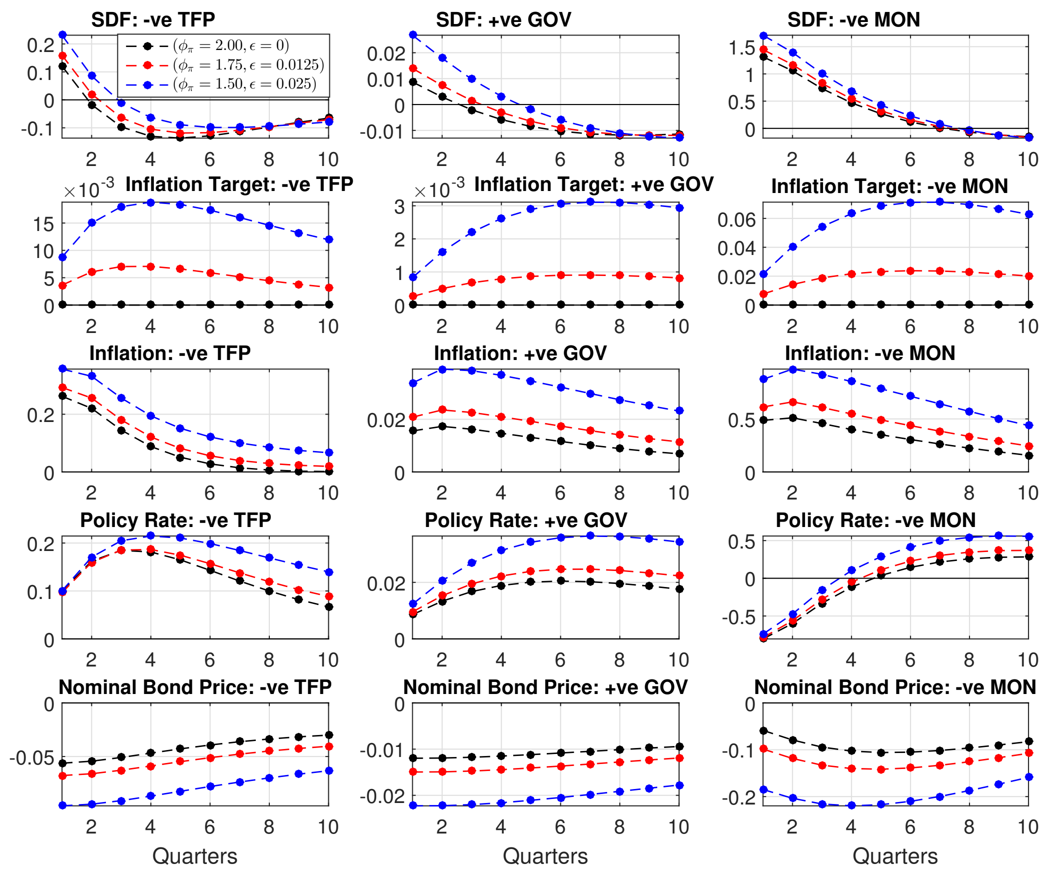
Notes: The figure reports the mean values for the 40 quarter nominal Government spot rate, 40 quarter nominal corporate spot rate and the credit spread (CS) implied by our model for various levels of long-run inflation risk. All yields are expressed at an annual rate.

Figure 3.15: Mean Equity Premium for Various Levels of Long-Run Inflation Risk



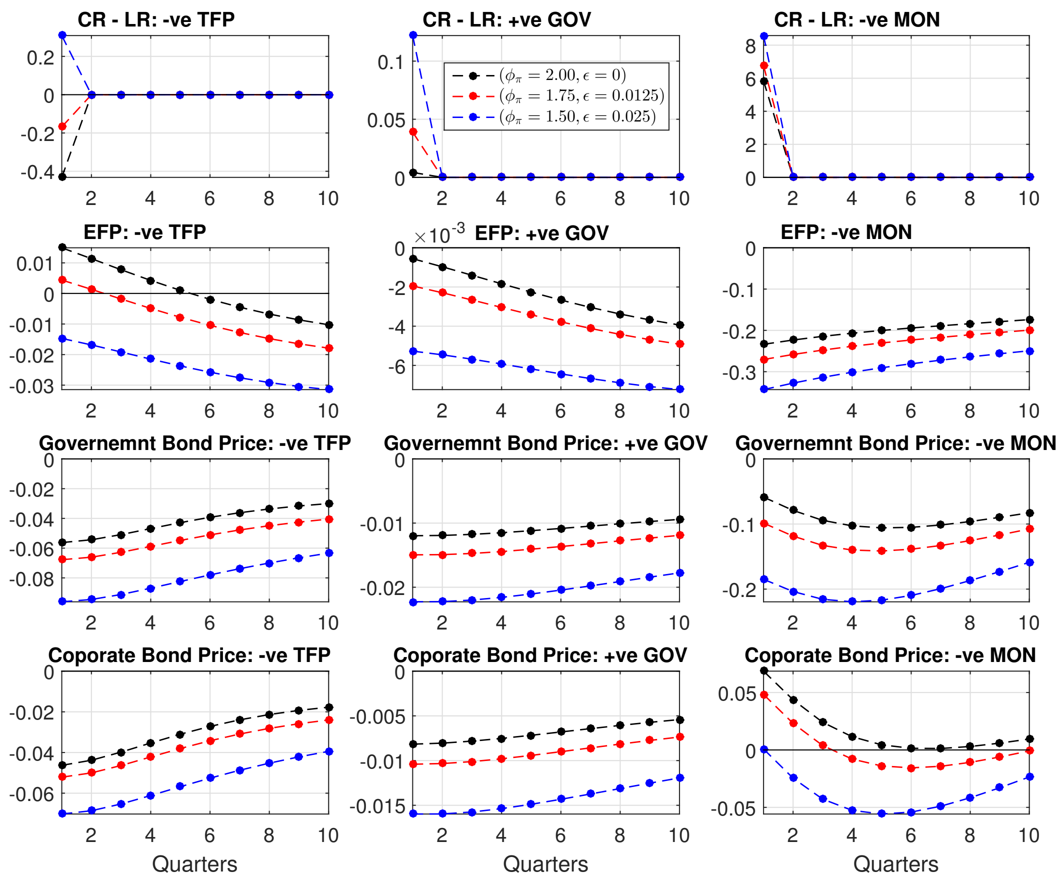
Notes: The figure reports the mean values for the quarterly equity return, quarterly real risk-free rate and the equity premium (EP) implied by our model for various levels of long-run inflation risk. All yields are expressed at an annual rate.

Figure 3.16: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



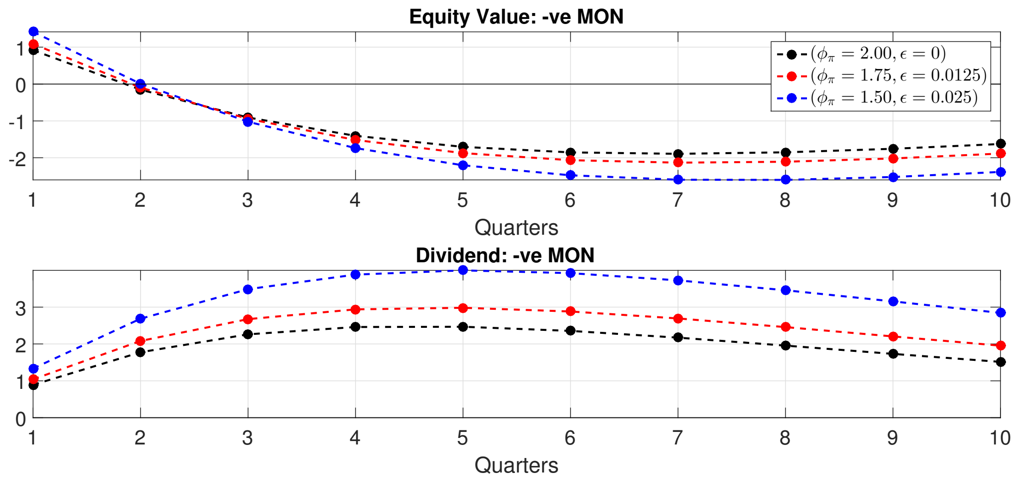
Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.17: Impulse Response Functions: $\zeta_t^a \downarrow$, $\zeta_t^g \uparrow$,$\zeta_t^r \downarrow$



Notes: The first, second and third columns report impulse response functions to a negative TFP shock, a positive Government spending shock and a negative monetary policy shock respectively. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

Figure 3.18: Impulse Response Functions: $\zeta_t^r \downarrow$



Notes: Presented are impulse response functions to a negative monetary policy shock. The y-axis denotes percentage deviations from the non-stochastic steady state and the x-axis denotes the quarters elapsed following the shock.

3.8 Appendices

3.A Stationary Non-Linear System

1. $U_t = \zeta_t^b \frac{\left(C_t - \frac{\gamma_c C_{t-1}}{\mathfrak{G}}\right)^{1-\sigma_c}}{1-\sigma_c} \exp\left\{\frac{\sigma_c - 1}{1+\sigma_h} H_t^{1+\sigma_h}\right\}$

2. $V_t = U_t + \beta \mathfrak{C}_t$

3. $\mathfrak{C}_t = \left(E_t V_{t+1}^{1-\varrho} \mathfrak{G}^{1-\sigma_c}\right)^{\frac{1}{1-\varrho}}$

4. $\lambda_t = \zeta_t^b \left(C_t - \frac{\gamma_c C_{t-1}}{\mathfrak{G}}\right)^{-\sigma_c} \exp\left\{\frac{\sigma_c - 1}{1+\sigma_h} H_t^{1+\sigma_h}\right\}$

5. $\Lambda_{t,t+1} = \bar{\beta} \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{V_{t+1} \mathfrak{G}^{1-\sigma_c}}{\left(\mathfrak{C}_t^{1-\varrho}\right)^{\frac{1}{1-\varrho}}}\right)^{-\varrho}$
   where $\bar{\beta} = \beta \mathfrak{G}^{-\sigma_c}$

6. $1 = E_t \left[\Lambda_{t,t+1} \frac{1}{\Pi_{t,t+1}}\right] R_{t,t+1}^N$

7. $1 = E_t \left[\Lambda_{t,t+1}\right] R_{t,t+1}^R$

8. $\left(\frac{W_t^*}{W_t}\right)^{1+\varepsilon_w \sigma_h} = \frac{\varepsilon_w}{\varepsilon_w - 1} \frac{\Xi_t^1}{\Xi_t^2}$

9. $\Xi_t^1 = \zeta_t^w \left(C_t - \frac{\gamma_c C_{t-1}}{\mathfrak{G}}\right) H_t^{1+\sigma_h} + \theta_w \mathfrak{G} E_t \left[\Lambda_{t,t+1} \mathfrak{M}_{t,t+1}^{-\varepsilon_w(1+\sigma_h)} \Xi_{t+1}^1\right]$

10. $\Xi_t^2 = W_t H_t + \theta_w \mathfrak{G} E_t \left[\Lambda_{t,t+1} \mathfrak{M}_{t,t+1}^{1-\varepsilon_w} \Xi_{t+1}^2\right]$

11. $\mathfrak{M}_{t-1,t} = \frac{\left(\Pi_{t-1,t}^{\dagger}\right)^{1-\iota_w} \Pi_{t-2,t-1}^{\iota_w}}{\Pi_{t-1,t}}$

12. $1 = (1-\theta_w) \left(\frac{W_t^*}{W_t}\right)^{1-\varepsilon_w} + \theta_w \mathfrak{M}_{t-1,t}^{1-\varepsilon_w}$

13. $\Delta_t^w = (1-\theta_w) \left(\frac{W_t^*}{W_t}\right)^{-\varepsilon_w} + \theta_w \mathfrak{M}_{t-1,t}^{-\varepsilon_w} \Delta_{t-1}^w$

14. $H_t = \frac{H_{i,t}}{\Delta_t^w}$

15. $1 = Q_t \zeta_t^i \left(1 - \Phi'\left(\frac{I_t \mathfrak{G}}{I_{t-1}}\right)\left(\frac{I_t \mathfrak{G}}{I_{t-1}}\right) - \Phi\left(\frac{I_t \mathfrak{G}}{I_{t-1}}\right)\right) + E_t \left[\Lambda_{t,t+1} \zeta_{t+1}^i Q_{t+1} \Phi'\left(\frac{I_{t+1}\mathfrak{G}}{I_t}\right)\left(\frac{I_{t+1}\mathfrak{G}}{I_t}\right)^2\right]$

16. $K_t = (1-\delta) \frac{K_{t-1}}{\mathfrak{G}} + \zeta_t^i \left(1 - \Phi\left(\frac{I_t \mathfrak{G}}{I_{t-1}}\right)\right) I_t$

17. $Y_{i,t} = \zeta_t^a \left(Z_t \frac{K_{t-1}}{\mathfrak{G}} \right)^\alpha H_t^{1-\alpha}$

18. $R^M_{t-1,t} = \frac{\alpha MC_t Y_{i,t} \mathfrak{G}}{K_{t-1}}$

19. $Z_t = \left(\frac{R^M_{t-1,t}}{Q_t R^M} \right)^{\sigma_z}$

20. $\delta\left[Z_t\right] = \delta + R^M \sigma_z \left(Z_t^{\frac{1}{\sigma_z}} - 1 \right)$

21. $W_t = \frac{(1-\alpha) MC_t Y_{i,t}}{H_t}$

22. $R^K_{t-1,t} = R^M_{t-1,t} + \frac{(1-\delta) Q_t}{Q_{t-1}}$

23. $R^L_{t,t+1} = F \left(\frac{Q_t K_t}{N_t} \frac{N}{K} \right)^\psi R^N_{t,t+1}$

24. $0 = E_t \left[\frac{1}{\Pi_{t,t+1}} R^L_{t,t+1} - R^K_{t,t+1} \right]$

25. $N_t = \varphi \left(R^K_{t-1,t} Q_{t-1} \frac{K_{t-1}}{\mathfrak{G}} - \frac{R^l_{t-1,t}}{\Pi_{t-1,t} \mathfrak{G}} \left(Q_{t-1} K_{t-1} - N_{t-1} \right) \right) + \mathfrak{N}$

26. $p_t^* = \frac{\varepsilon_p}{\varepsilon_p - 1} \frac{\kappa_t^2}{\kappa_t^1}$

27. $\kappa_t^2 = \zeta_t^p MC_t Y_t + \theta_p \mathfrak{G} E_t \Lambda_{t,t+1} \mathfrak{W}^{-\varepsilon_p}_{t,t+k} \kappa^2_{t+1}$

28. $\kappa_t^1 = Y_t + \theta_p \mathfrak{G} E_t \Lambda_{t,t+1} \mathfrak{W}^{1-\varepsilon_p}_{t,t+k} \kappa^1_{t+1}$

29. $\mathfrak{W}_{t-1,t} = \frac{\left(\Pi^\dagger_{t-1,t}\right)^{1-\iota_p} \Pi^{\iota_p}_{t-2,t-1}}{\Pi_{t-1,t}}$

30. $1 = (1-\theta_p) \left(p_t^*\right)^{1-\varepsilon_p} + \theta_p \mathfrak{W}^{1-\varepsilon_p}_{t-1,t}$

31. $\Delta_t^p = (1-\theta_p) \left(p_t^*\right)^{-\varepsilon_p} + \theta_p \mathfrak{W}^{-\varepsilon_p}_{t-1,t} \Delta^p_{t-1}$

32. $Y_t = \frac{Y_{i,t}}{\Delta_t^p}$

33. $\frac{R^N_{t,t+1}}{R^N} = \left(\frac{R^N_{t-1,t}}{R^N} \right)^{\iota_r} \left(\left(\frac{\Pi_{t-1,t}}{\Pi^\dagger_{t-1,t}} \right)^{\phi_\Pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_y} \right)^{1-\iota_r} \zeta_t^r$

34. $\Pi^\dagger_{t-1,t} = (1-\rho_\pi) \Pi^\dagger + \rho_\pi \Pi^\dagger_{t-2,t-1} + \epsilon \left(\Pi_{t-2,t-1} - \Pi^\dagger_{t-2,t-1} \right)$

35. $Y_t = C_t + I_t + \zeta_t^g g Y$

3.B Steady State

From 16.

$$Q = 1 \tag{SS1}$$

From 20.

$$Z = 1 \tag{SS2}$$

From 30.

$$\mathfrak{W} = 1 \tag{SS3}$$

From 11.

$$\mathfrak{M} = 1 \tag{SS4}$$

From 30.

$$p^* = 1 \tag{SS5}$$

From 31.

$$\Delta^p = 1 \tag{SS6}$$

From 26., 27. and 28.

$$MC = \frac{\varepsilon_p - 1}{\varepsilon_p} \tag{SS7}$$

From 5.

$$\Lambda = \bar{\beta} \tag{SS8}$$

From 7.

$$R^R = \frac{1}{\Lambda} \tag{SS9}$$

From 6.[26]

$$R^N = \frac{\Pi}{\Lambda} \tag{SS10}$$

[26] Note that Π is exogenously given.

From 23.[27]

$$R^L = F \cdot R^N \tag{SS11}$$

From 24.

$$R^K = \frac{R^L}{\Pi} \tag{SS12}$$

From 16.

$$\frac{I}{K} = 1 - \frac{(1-\delta)}{\mathfrak{G}} \tag{SS13}$$

From 18. and 22.

$$\frac{Y}{K} = \frac{R^K - (1-\delta)}{\alpha MC\mathfrak{G}} \tag{SS14}$$

From 17.

$$\frac{H}{K} = \left(\frac{Y}{K}\right)^{\frac{1}{1-\alpha}} \mathfrak{G}^{\frac{\alpha}{1-\alpha}} \tag{SS15}$$

From 21.

$$W = (1-\alpha)\, MC \left(\mathfrak{G}\frac{H}{K}\right)^{-\alpha} \tag{SS16}$$

From 13.

$$W^* = W \tag{SS17}$$

From 35.

$$\frac{C}{K} = \frac{Y}{K}(1-g) - \frac{I}{K} \tag{SS18}$$

From 8., 9. and 10.

$$C = \frac{\varepsilon_w - 1}{\varepsilon_w} W H^{-\sigma_h} \left(1 - \frac{\gamma_c}{\mathfrak{G}}\right)^{-1}$$

$\Longrightarrow$

$$K^{1+\sigma_h}\frac{C}{K} = \frac{\varepsilon_w - 1}{\varepsilon_w} W \left(\frac{H}{K}\right)^{-\sigma_h} \left(1 - \frac{\gamma_c}{\mathfrak{G}}\right)^{-1}$$

[27] Note that F is exogenously given.

$\Longrightarrow$

$$K = \left(\frac{\varepsilon_w - 1}{\varepsilon_w} W \left(\frac{H}{K} \right)^{-\sigma_h} \left(\frac{C}{K} \right)^{-1} \left(1 - \frac{\gamma_c}{\mathfrak{G}} \right)^{-1} \right)^{\frac{1}{1+\sigma_h}} \tag{SS19}$$

With K it is straightforward to solve for the remaining steady state values.

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