A structural decomposition of the South African yield curve

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Abstract

This paper extends the existing body of South African literature on the yield curve in four respects: Firstly, the macroeconomic shocks that have contributed to developments in the yield curve during the inflation targeting regime of the South African Reserve Bank is analysed within the context of a structural New Keynesian DSGE model. Secondly, the yield spread is decomposed into two subcomponents: the expected spread and the term premium. Moreover, whereas the literature to date has studied the predictive power of the aggregate yield spread with respect to economic activity, this paper goes further by distinguishing between the individual predictive ability of its subcomponents, i.e. the expected spread and the term premium. Finally, the model's ability to forecast South African 10-year government bond yields is evaluated against the accuracy of professional forecasters as polled by Reuters, and found to be superior after the first quarter of the forecast horizon.

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Preliminary and incomplete. Please do not quote.

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1 Introduction

The behaviour of interest rates at various maturities, more formally known as the *yield curve*, has intrigued economists from as early as Mitchell (1913). After Kessel (1965) had noted how movements in the yield curve corresponded to business cycle peaks and troughs, a substantial literature developed around the yield curve's ability to predict changes in economic activity. Although there exists some variation over time and across countries, the general consensus that has emerged from this literature is that the *yield spread* (*i.e.* the difference between interest rates on long-term and short-term bonds) has the ability to predict both the future level of output as well as the timing of turning points in the business cycle.[1]

Formal models aimed at characterising the yield curve itself first emerged from within the finance literature, where Vasicek (1977), Cox et al. (1985) and Nelson and Siegel (1987) are regarded as landmarks. Generally, these models relate the entire yield curve to three latent factors that capture its level, slope and curvature, while the latent factors themselves are usually functions of the yields too. Although the value of these models from an asset pricing perspective cannot be denied, they are fairly silent with respect to the actual macroeconomic dynamics that are driving the shape of the yield curve.[2] Addressing this issue, Evans and Marshall (1998) make use of a structural vector autoregression (SVAR) to identify the reaction of the yield curve in response to monetary policy shocks. The authors find that these shocks do affect the yield curve, especially at the short end. Yet, monetary policy only accounts for a small proportion of the yield curve's variance. Similarly, Ang and Piazzesi (2003) extend the traditional latent-factor approach to include a wider set of macroeconomic variables. Their results indicate that inflation is the overriding determinant of movements in the yield curve. In addition, they find that the inclusion of macroeconomic variables significantly improves the model's ability to forecast yields.

In recent years a number of studies have turned to the lens of a New Keynesian DSGE model in order to analyse the impact of macroeconomic dynamics on the yield curve. Within the standard New Keynesian setting, the rational expectations solution to the model facilitates the derivation of expected future short-term interest rates. This allows for a characterisation of the yield curve that is consistent with the expectations hypothesis, which in turn states that the yield of a given maturity should equal the average of expected short term rates over the period until maturity. Accordingly, De Graeve et al. (2009) use the Smets and Wouters (2007) model in this manner to provide a macroeconomic interpretation of historical developments in the US yield curve. However, the expectations hypothesis posits that bonds of different maturities are perfect substitutes which, in turn, implies that the slope of the yield curve is flat on average. Empirically, however, the yield curve tends to slope upwards on average (see Mishkin, 2007). This empirical shortcoming of the expectations hypothesis in explaining the upward-sloping nature of the yield curve is addressed by the liquidity premium theory. It extends the expectations hypothesis by assuming that bonds of different maturities are not perfect substitutes, as investors generally prefer to hold shorter-term bonds given the increasing interest rate risk that they face when holding longer-term bonds. As a result, in order to be induced to hold longer-term bonds, investors require a *liquidity* or *term premium* that will compensate them for the additional risk. It is this term premium – which increases

[1] See Wheelock and Wohar (2009) for a comprehensive survey.

[2] See, for instance Duffie and Kan (1996).

along with the maturity of the bond – that explains the tendency of the yield curve to slope upwards. Hence, in order to create endogenous deviations from the expectations hypothesis within the New Keynesian framework, or *term premiums*, Andrés et al. (2004) assume imperfect asset substitutability *a la* Tobin (1969) between money and bonds of different maturities. Moreover, the authors show that within this expanded model structure where longer-term yields deviate from those dictated by the expectations hypothesis, central bank operations have an effect on the relative prices of financial assets. In turn, these changes in relative prices affect longer-term yields – the *unconventional* channel of monetary policy which Bernanke had already alluded to in 2002. With a similar motive – to create endogenous term premiums – Rudebusch and Swanson (2012) assume that households exhibit Epstein-Zin preferences, as opposed to the standard preference specification typically found in New Keynesian models.[3] This specification is sufficient to generate the large and time-varying term premiums that are often observed in US data. In addition, from a structural point of view, Rudebusch and Swanson (2012) find that shocks which drive output and prices in opposite directions, for instance shocks to technology and supply, explain a significant proportion of the movement in the US yield spread.

The South African literature on the yield curve has to date largely focused on its relationship with real economic activity. Using cointegration analysis, Nel (1996) compiled the first empirical study on the matter and found that a statistically-significant positive relationship existed between the yield spread on South African 10-year government bonds and GDP. Building on this proven empirical relationship, Moolman (2002) investigated the ability of the yield spread to predict turning points in the South African business cycle with the use of a probit model. The model correctly predicted 7 of the 8 eight turning points that occurred between 1979 and 2001. On average, the probit model predicted these turning points with a lead of two quarters. Moreover, Khomo and Aziakpono (2007) extended Moolman's (2002) result by comparing the predictive power of the term spread to that of other potential indicators of economic activity, such as real growth in M3 money supply, the All-Share index of the Johannesburg Securities Exchange (JSE), and the leading indicator of the South African Reserve Bank (SARB). Apart from the superiority of the SARBs leading indicator in the four months prior to the turning point, their results indicate that, over longer horizons the yield spread is the more reliable predictor of recessions. Finally Bonga-Bonga (2010) – diverting from the yield spread-GDP literature – used a structural vector autoregression (SVAR) to examine the reaction of the yield curve to demand, supply and monetary policy shocks. The study concludes that, following a demand or monetary policy shock, short and long-term rates move in the same direction. However, short-term rates rise while long-term rates fall in response to a positive supply shock, which contradicts the prediction of Ellingsen and Söderström's (2001) structural model: that supply shocks will cause these rates move in the same direction.

This paper extends the existing body of South African literature on the yield curve in five respects: Firstly, the macroeconomic shocks that have contributed to developments in the yield curve during the inflation targeting regime of the South African Reserve Bank are analysed within the context of a structural New Keynesian DSGE model. Secondly, the model is used to decompose the yield on South African 10-year government bond into a term premium and a component related to the expected future short-term rates. Thirdly, whereas the literature to date has studied the predictive power of the aggregate

[3]Under the standard habit preferences, households are only concerned with sudden changes in consumption, while under Epstein-Zin preferences, it is changes over the medium to longer term that matter as well.

yield spread with respect to economic activity, this paper goes further by distinguishing between the predictive ability of its subcomponents, i.e. the expected spread and the term premium. Finally, the model's ability to forecast South African 10-year government bond yields will be evaluated against the accuracy of professional forecasters.

The remainder of the paper is laid out as follows: In Section 2 the yield curve extension to the DSGE model is discussed. Section 3 covers both the estimation methodology and results. Thereafter, the model's interpretation of the structural shocks that contributed to historical developments in the 10-year yield spread is analysed. In Section 5, the rational expectations solution of the model is used to decompose the 10-year yield into its expectations-hypothesis component and the term premium, whereafter the dynamic reaction of the yield curve and its subcomponents are discussed. Finally, before concluding, there are two sections that analyse the DSGE model's ability to forecast the yield curve, as well as the yield curve's ability to predict future GDP.

2 The model

The model developed in Chapter 1 is extended to incorporate the South African yield curve into the rigorous structure of a small open economy DSGE model. Consequently, whereas the asset portfolio of households in Chapter 1 consisted solely of domestic and foreign one-period bonds, they are now assumed to hold two additional assets: money and L-period zero-coupon bonds ($B_{L,t}$).[4] As before, the one-period bond pays a gross return of R_t while, following Andrés et al. (2004), it is assumed that households hold their long-term bonds until they mature in period $t+L$, at which point these bonds yield a gross return of $(R_{L,t})^L$.[5]

In order to ensure positive holdings of both one-period and L-period bonds in equilibrium – irrespective of differences in yield – the model incorporates imperfect substitutabilty among assets, largely motivated by the work of Tobin (1958, 1969 and 1982). As a result, following Marzo et al. (2008) and Zagaglia (2009), it is assumed that bond trading is costly for the household, and hence, it pays the following quadratic adjustment cost when purchasing the long-term bond:

$$AC_t^b = \frac{\phi_L}{2}\left(\frac{b_{L,t}}{b_{L,t-1}}\right)^2 y_t. \tag{1}$$

The adjustment cost is measured in terms of stationary real bond holdings and may be interpreted as transaction costs on bond trading, which are paid in terms of output.[6] This formulation facilitates variations in the spread between the one-period and long-term bond, both in equilibrium and over time. The magnitude of the adjustment cost parameter ϕ_L reflects the opportunity cost associated with holding a bond of longer maturity. As such, $\phi_L > 0$, and $R_L > R$.

Moreover, the household's money holdings are directly affected by its holding of long-term bonds.

[4]For the purposes of this paper, $L = 40$ such that the L-period bonds represent South African 10 year government bonds.

[5]The assumption that L-period bonds are zero-coupon corresponds to their general treatment in macroeconomic models (see, amongst others, Svensson (2000), Andrés et al. (2004) and Bekaert et al. (2010)). As a further simplification it is then assumed that these bonds are held until maturity. Without these two simplifying assumptions, both the budget constraint and first-order condition for long-term bond holdings would contain an additional $2L$ terms.

[6]$b_{L,t} = B_{L,t}/(z_t P_t^d)$.

Andrés et al. (2004) argue that households experience a loss of liquidity when purchasing bonds of maturities in excess of one period. As a result, they compensate for this loss of liquidity by holding additional money. This friction can therefore be represented as an adjustment cost function between the relative holdings of money and the L-period bond, as follows:

$$AC_t^m = \frac{\nu_L}{2}\left(\frac{m_t}{b_{L,t}}\kappa_L - 1\right)^2 y_t \tag{2}$$

where κ_L is the inverse of the steady state ratio m/b_L, such that the adjustment cost is zero in the steady state.

Consequently, against the background of its expanded asset portfolio, the representative household maximises the following intertemporal utility function:[7]

$$E_0^j \sum_{t=0}^{\infty} \beta^t \left[\xi_t^c \ln\left(C_t - bC_{t-1}\right) - \xi_t^h A_L \frac{(h_t)^{1+\sigma_L}}{1+\sigma_L} + A_m \frac{m_t^{1-\sigma_m}}{1-\sigma_m}\right] \tag{3}$$

subject to the budget constraint:

$$\begin{aligned} M_t(1+AC_t^m) + \frac{B_t}{R_t} + \frac{B_{L,t}}{(R_{L,t})^L}(1+AC_t^b) + \frac{S_t B_{j,t}^*}{R_t^* \Phi\left(\frac{A_t}{z_t}, S_t, \tilde{\phi}_t\right)} + P_t^c C_t + P_t^i I_t + P_t^d \left[a(u_t)K_{t-1} + P_t^{k'}\Delta_t\right] \\ = M_{t-1} + B_{t-1} + B_{L,t-L} + S_t B_{t-1}^* + W_t h_t + R_t^k u_t K_t + \Pi_t - T_t. \end{aligned} \tag{4}$$

Within the utility function, C_t and h_t denote household consumption and labour supply, while $m_t = M_t/(z_t P_t^d)$ denotes its stationary real cash holdings. The additional parameters A_m and σ_m respectively pin down steady state money holdings and determine the curvature of money demand. Moreover, the expression on the left of the equality in Equation (4) represents nominal expenditure by the household in period t, while the right-hand side of the equality captures nominal income earned by the household in period t as well as wealth carried over from $t-1$. Hence, households purchase new domestic and foreign assets (where the bond prices are inversely proportional to their respective gross nominal interest rates), nominal consumption goods, nominal investment goods, they pay adjustment costs on capital utilisation and also purchase installed capital. The wealth households carry over from $t-1$ consists of cash holdings as well as their maturing domestic and foreign bond portfolio. Households are remunerated for the labour they supply and the capital services they rent to firms. In addition, they receive profits from firm ownership, Π_t, while they pay nominal lump-sum taxes to the government, T_t.

First-order conditions Optimising Equations (3) and (4) with respect to the two additional assets – money and L-period bonds – yields the following first-order conditions:

[7] Since households make identical aggregate choices in equilibrium, the subscript j used to denote the representative household in Chapter 1 is dropped here for notational convenience.

Money holdings, m_t

$$E_t\left[\frac{\beta\psi^z_{t+1}}{\pi_{t+1}\mu^z_{t+1}}\right]+A_m m_t^{-\sigma_m}-\psi^z_t\left\{1+AC^m_t+\left[\nu_L\kappa_L\left(\frac{m_t}{b_{L,t}}\kappa_L-1\right)\frac{m_t}{b_{L,t}}\right]y_t\right\}=0 \tag{5}$$

Holdings of L-period bonds, $b_{L,t}$

$$\begin{aligned}&E_t\left[\frac{\psi^z_{t+L}\left(\beta R_{L,t}\right)^L}{\prod_{k=1}^L\left(\pi_{t+k}\mu^z_{t+k}\right)}+\beta\phi_L\psi^z_{t+1}\left(\frac{R_{L,t}}{R_{L,t+1}}\right)^L\left(\frac{b_{L,t+1}}{b_{L,t}}\right)^3 y_{t+1}\right]\\&-\psi^z_t\left[1+\frac{3}{2}\phi_L\left(\frac{b_{L,t}}{b_{L,t-1}}\right)^2 y_t-\nu_L\kappa_L\left(R_{L,t}\right)^L\left(\frac{m_t}{b_{L,t}}\kappa_L-1\right)\left(\frac{m_t}{b_{L,t}}\right)^2 y_t\right]=0\end{aligned} \tag{6}$$

2.1 Government

In every period, the government finances its expenditure by issuing new one-period and L-period bonds, as well as raising taxes. Its period expenses consist of nominal general government expenditure $P^d_t G_t$ and also the repayment of maturing bonds. In addition, government controls the money supply. Consequently, the real (stationary) budget constraint of the government is expressed as follows:

$$\frac{\frac{B_t}{R_t}+\frac{B_{L,t}}{\left(R_{L,t}\right)^L}+M_t+T_t}{z_t P^d_t}=\frac{B_{t-1}+B_{L,t-L}+M_{t-1}+P^d_t G_t}{z_t P^d_t} \tag{7}$$

Moreover, let the government's total liabilities, ℓ_t, be defined as follows:

$$\ell_t=\frac{1}{z_t P^d_t}\left(B_{t-1}+B_{L,t-L}+M_{t-1}\right). \tag{8}$$

In order to ensure dynamic stability, where inflation does not emerge as a fiscal phenomenon (see Leeper, 1991) , it is assumed that taxation by government is determined by the deviation of its outstanding liabilities from their steady state values:

$$\tau_t=\psi_0+\psi_1\left(\ell_t-\ell\right) \tag{9}$$

where $\tau_t=T_t/(z_t P^d_t)$. Accordingly, Equation (9) implies that taxes cannot be set independently from the level of outstanding government debt. This, in turn, rules out any possibility of an explosive path for government debt. Finally, both government expenditure and the supply of L-period bonds are assumed to follow AR(1) processes.

2.2 The central bank

As a further extension to Chapter 1, it is assumed that the central bank does not only consider inflation and ouput when setting the policy rate, but it also takes account of the growth rate in money:

$$\hat{R}_t=\rho_R\hat{R}_{t-1}+(1-\rho_R)\left[\hat{\bar{\pi}}^c_t+\phi_\pi\left(\hat{\pi}^{c,4}_{t+1}-\hat{\bar{\pi}}^c_t\right)+\phi_{\Delta\pi}\hat{\pi}^c_t+\phi_y\hat{y}_t+\phi_{\Delta y}\Delta\hat{y}_t+\phi_{\Delta m}\Delta\hat{m}_t\right]+\varepsilon^R_t. \tag{10}$$

The inclusion of money in the Taylor rule follows Andrés et al. (2004) and is largely motivated by the fact that growth in money serves as a potential precursor to future inflation.

2.3 Aggregate demand

Finally, clearing in the domestic final goods market requires that the supply of the final good firm matches the demand from households, government and the export market, after taking account of the additional adjustment costs on L-period bonds and money that are paid in terms of output:

$$y_t = \varepsilon_t \left(\frac{k_t^s}{\mu_t^z}\right)^{\alpha} H_t^{1-\alpha} - \phi - a(u_t)\left(\frac{k_{t-1}}{\mu_t^z}\right) - \left[\frac{\phi_l}{2}\left(\frac{b_{L,t}}{b_{L,t-1}}\right)^2 + \frac{\nu_L}{2}\left(\frac{m_t}{b_{L,t}}\kappa_L - 1\right)^2\right] y_t, \tag{11}$$

where $y_t = c_t^d + c_t^d + g_t + c_t^x + i_t^x$.[8]

3 Estimation

3.1 Data

In addition to the fifteen observable domestic and international macro-economic time series used to estimate the model in Chapter 1, two additional variables are now included. They are the yield on South African 10 year government bonds and M1 money supply. As before, the dataset spans the period from 2000Q1 to 2012Q4, which coincides with the inflation targeting regime of the South African Reserve Bank (SARB). Table 1 contains a summary of the data series used, as well as their respective sources.

3.2 Measurement issues

Based on the assumption that a proportion of the fluctuation in government bond yields are driven by exogenous factors (see Tobin, 1982) which cannot be explained by the macroeconomic structure of the model, the 10 year yield's measurement equation includes a measurement error $\eta_{L,t}$ as in De Graeve et al. (2009):

$$\tilde{R}_{L,t} = \ln(R_L) + \hat{R}_{L,t} + \eta_{L,t} \tag{12}$$

The standard deviation of the measurement error is calibrated such that 10 per cent of the variation in the 10 year government bond yield is accounted for by *exogenous* factors.[9]

3.3 Calibration

The model is estimated with Bayesian techniques, which, in addition to being the most popular approach for estimating DGSE models, has numerous benefits (see, for example, An and Schorfheide, 2007, Lubik and Schorfheide, 2005 and Sims, 2008). Nevertheless, a number of parameter values are calibrated. This

[8] See the Appendix for the model's entire set of log-linearised equations.
[9] The full set of 17 measurement equations are reported in the Appendix.

Table 1: Observable variables

Variable	Series	Source
South Africa		
$\Delta\ln(\tilde{Y}_t)$	Real Gross Domestic Product	South African Reserve Bank
$\Delta\ln(\tilde{C}_t)$	Private consumption	
$\Delta\ln(\tilde{I}_t)$	Total fixed investment	
$\Delta\ln(\tilde{X}_t)$	Total exports	
$\Delta\ln(\tilde{M}_t)$	Total imports	
$\Delta\ln(\tilde{S}_t)$	Nominal effective exchange rate	
$\Delta\ln(\tilde{E}_t)$	Non-agricultural employment	
$\Delta\ln(\tilde{W}_t)$	Compensation of employees	
$\tilde{\pi}_t^i$	Fixed investment deflator	
$\tilde{R}_t$	Repo rate	
$\tilde{R}_{L,t}$	10 year government bond yield	
$\Delta\ln(\tilde{M1}_t)$	M1 money supply	
$\tilde{\pi}_t^c$	Consumer price inflation	StatsSA
$\tilde{\pi}_t^d$	Producer price inflation, domestic manufacturing	
$\tilde{\bar{\pi}}_{t+1}^c$	Inflation target midpoint	Author's own calculations
Foreign economy		
$\Delta\ln(\tilde{Y}_t^*)$	Gross Domestic Product (trade weighted)	GPM, CEPREMAP
$\tilde{\pi}_t^*$	Consumer price inflation (trade weighted)	
$\tilde{R}_t^*$	Policy interest rates (trade weighted)	

is motivated by two factors: either the parameter is crucial for pinning down a specific steady state value, or there is insufficient identification of the parameter.[10]

Except for the two parameters related to the yield curve, the calibrated parameter values are similar to Chapter 1. Hence, as before, the discount factor β is calibrated to 0.9975. The deprecation rate δ is set to 0.025, which implies an annual depreciation of capital of 10 per cent. The constant in the disutility of labour, A_L, is calibrated to 7.5 which implies that households devote more or less 30 per cent of their time to working, while the calibration of the inverted Frisch elasticity of labour supply at 5 follows Martínez-García et al. (2012). Altig et al. (2011) estimate the parameter that governs the adjustment cost of capital utilisation, σ_a, at 2.02, while Adolfson et al. (2007) calibrate it to 1,000,000 – which effectively removes the capital utilisation channel from the model. Based on a comparison of the model's log marginal likelihood using both Altig et al. (2011) and Adolfson et al.'s 2007 capital utilisation parameter values, as well as some intermediate ones, the parameter is ultimately set to 10. The share of capital used in production α is set to 0.23 to ensure that the model's steady state ratios for both consumption and investment to GDP match their respective sample means of 60 and 20 per cent. Similarly, the shares of imports in aggregate consumption and investment, ϑ_c and ϑ_i, are calibrated such that the model's steady state ratios of total imports and exports to GDP match their sample means of roughly 27 per cent. The parameters that guide the persistence in wage setting, θ_w and κ_w, are not identified and as a result are both calibrated to 0.75 – implying that wage contract are re-optimised once

[10]Identification analysis of the model's parameters was carried out using the identification toolbox in Dynare, which is largely based on Iskrev (2010a, 2010b) as well as Andrle (2010).

Table 2: Calibrated parameters

β	Discount factor	0.9975	δ	Depreciation rate	0.025
A_L	Labour disutility constant	7.5	σ_L	Labour supply elasticity	5
σ_a	Capital utilisation cost	10	α	Capital share in production	0.23
ϑ_c	Consumption imports share	0.36	ϑ_i	Investment imports share	0.48
θ_w	Calvo: wage setting	0.69	κ_w	Indexation: wage setting	0.5
λ_w	Wage setting markup	1.05	λ_d	Domestic price markup	1.1
η_c	Subst. elasticity: consumption	1.5	η_i	Subst. elasticity: investment	1.5
η_f	Subst. elasticity: foreign	1.25	μ^z	Permanent technology growth	1.0085
π	Inflation	1.0114	g_y	Government spending persistence	0.815
ρ_g	Government spending to GDP	0.197	π^*	Foreign inflation	1.005
Yield curve					
ϕ_L	Long bond adjustment cost	0.09	κ_L	Steady state ratio: L-period bonds/money	0.2861

every four quarter, with a high degree of indexation to past inflation. The steady state wage markup follows Adolfson et al. (2007) and is set at 1.05, while the markup for domestic prices is calibrated to 1.1. Estimates of the substitution elasticities for consumption, investment and foreign goods generally vary between 1 and 2, and are therefore calibrated to 1.5, 1.5 and 1.25 respectively. The steady state growth rate of the model's stochastic trend, μ^z, is set to 1.0085, which implies a steady state economy-wide growth rate of 3.4 per cent – roughly the average growth rate of GDP over the sample. Steady state growth of money, μ^m, is set to 1.02, *i.e.* an annualised rate of 8 per cent. Moreover, the steady state rate of inflation π in the model is calibrated to yield an annual rate of 4.5 per cent. The nominal interest rate in steady state is $R = (\pi\mu^z)/\beta$. Hence, the calibrations for β, μ^z and μ^m together imply an annualised steady state nominal interest rate of 8.9 per cent – its sample mean. The persistence of government spending is set to an OLS estimate of the AR(1) coefficient for government spending, while the steady state ratio of government spending to GDP, g_y, matches its sample mean. The calibration for steady state foreign inflation implies an annualised rate of 2 per cent. The parameter that determines the L-period bond adjustment cost, ϕ_L, is calibrated at 0.09 in order to match the 9.38 per cent sample mean of the 10 year government bond yield. It can be shown that in the steady state, while making use of the fact that $R = (\pi\mu^z)/\beta$, the first-order condition for L-period bond holdings in Equation (6) is:

$$R_L = R\left[1+\phi_L\left(\frac{3}{2}-\beta\right)y\right]^{\frac{1}{L}}$$

Hence setting the adjustment cost parameter ϕ_L to 0.09 implies a steady state (annualised) 10 year government bond yield of 9.35 per cent and, in turn, a steady state term premium of 45 basis points. Finally, the steady state ratio of L-period bonds to money holdings, κ_L, is calibrated to reflect the historical average of outstanding government bonds with a maturity of 10 years and over as a share of the total.

3.4 Priors

The yield curve extension of the model implies that four additional parameters need to be estimated, *i.e.* when compared to the set of parameter estimates from Chapter 1. Firstly, the prior for the elasticity of

Table 3: Priors and posterior estimation results

Parameter description		Prior			Posterior	
		Density[a]	Mean	Std. Dev.	Mean	90% interval
Adjustment costs						
ϕ_i	Investment	N	7.694	1.5	10.177	[8.020 ; 12.08]
Consumption						
b	Habit formation	B	0.65	0.1	0.828	[0.776 ; 0.884]
Calvo parameters						
θ_d	Domestic prices	B	0.715	0.05	0.872	[0.840 ; 0.904]
θ_{mc}	Imported consumption prices	B	0.675	0.1	0.814	[0.742 ; 0.882]
θ_{mi}	Imported investment prices	B	0.675	0.1	0.804	[0.747 ; 0.865]
θ_x	Export prices	B	0.675	0.1	0.620	[0.530 ; 0.717]
θ_E	Employment	B	0.675	0.1	0.795	[0.742 ; 0.849]
Indexation						
κ_d	Domestic prices	B	0.5	0.15	0.073	[0.029 ; 0.121]
κ_{mc}	Imported consumption prices	B	0.5	0.15	0.309	[0.133 ; 0.480]
κ_{mi}	Imported investment prices	B	0.5	0.15	0.263	[0.104 ; 0.412]
Exchange rate						
ϕ_a	Risk premium	IG	0.01	Inf	0.007	[0.003 ; 0.012]
ϕ_s	Modified UIP	U	0.5	[0,1]	0.211	[0.081 ; 0.336]
Taylor Rule						
ρ_R	Smoothing	B	0.8	0.05	0.895	[0.869 ; 0.923]
ϕ_π	Inflation	G	1.7	0.15	1.704	[1.472 ; 1.928]
$\phi_{\Delta\pi}$	Inflation (change)	G	0.3	0.1	0.281	[0.145 ; 0.423]
ϕ_y	Output gap	G	0.25	0.05	0.383	[0.292 ; 0.472]
$\phi_{\Delta y}$	Output gap (change)	G	0.125	0.05	0.130	[0.050 ; 0.212]
$\phi_{\Delta m}$	Money growth	G	1.38	0.27	0.391	[0.282 ; 0.507]
L-period bond						
ν_l	Money/bonds substitution elasticity	G	0.2	0.05	0.235	[0.158 ; 0.311]
Persistence parameters						
ρ_{μ^z}	Permanent technology	B	0.75	0.1	0.826	[0.748 ; 0.907]
ρ_ε	Transitory technology	B	0.75	0.1	0.916	[0.883 ; 0.952]
ρ_i	Investment technology	B	0.75	0.1	0.751	[0.653 ; 0.860]
$\rho_{\tilde{z}^*}$	Asymmetric technology	B	0.75	0.1	0.840	[0.698 ; 0.949]
ρ_c	Consumption preference	B	0.75	0.1	0.962	[0.929 ; 0.988]
ρ_H	Labour supply	B	0.75	0.1	0.341	[0.227 ; 0.446]
ρ_a	Risk premium	B	0.75	0.1	0.659	[0.543 ; 0.789]
ρ_{λ^d}	Imported cons. price markup	B	0.75	0.1	0.199	[0.130 ; 0.267]
$\rho_{\lambda^{mc}}$	Imported cons. price markup	B	0.75	0.1	0.754	[0.611 ; 0.898]
$\rho_{\lambda^{mi}}$	Imported invest. price markup	B	0.75	0.1	0.693	[0.531 ; 0.865]
ρ_{λ^x}	Export price markup	B	0.75	0.1	0.665	[0.494 ; 0.833]
ρ_L	L-period bond supply	IG	0.75	0.1	0.845	[0.739 ; 0.951]
Structural shocks						
σ_{μ^z}	Permanent technology	IG	0.4	Inf	0.286	[0.195 ; 0.372]
σ_ε	Transitory technology	IG	0.7	Inf	3.391	[2.041 ; 4.809]
σ_i	Investment technology	IG	0.4	Inf	0.353	[0.253 ; 0.456]
$\sigma_{\tilde{z}^*}$	Asymmetric technology	IG	0.4	Inf	0.404	[0.168 ; 0.600]
σ_c	Consumption preference	IG	0.4	Inf	0.126	[0.086 ; 0.166]
σ_H	Labour supply	IG	0.2	Inf	0.461	[0.355 ; 0.560]
σ_a	Risk premium	IG	0.5	Inf	1.672	[1.196 ; 2.163]
σ_d	Domestic price markup	IG	0.3	Inf	1.223	[1.002 ; 1.441]
σ_{mc}	Imported cons. price markup	IG	0.3	Inf	0.797	[0.576 ; 0.998]
σ_{mi}	Imported invest. price markup	IG	0.3	Inf	0.555	[0.268 ; 0.820]
σ_x	Export price markup	IG	0.3	Inf	1.635	[1.090 ; 2.153]
σ_R	Monetary policy	IG	0.15	Inf	0.159	[0.127 ; 0.188]
σ_L	L-period bond supply	IG	1.65	Inf	3.020	[2.214 ; 3.794]

[a] B – Beta, G – Gamma, IG – Inverse Gamma, N – Normal, U – Uniform

substitution between money and bonds, v_L, is assumed to follow a gamma distribution around a mean of 0.2 in Table 3. Marzo et al. (2008) calibrate this parameter to 0.5 for the US, while Zagaglia (2009) estimates it at 0.3 for the Euro Area. Secondly, the weight on money growth in the Taylor rule is assumed to be gamma distributed around a mean 1.38 – Andrés et al.'s (2004) estimate for this parameter. Finally, the persistence of the AR(1) process for L-period bond supply is assumed to follow a beta distribution around 0.75, while the standard error of its shock has an inverse-gamma distribution with a mean of 1.65.[11]

The remaining parameters' prior means and densities are similar to Chapter 1. Hence, as before the prior for the investment adjustment cost parameter ϕ_i in Table 3 is assumed to follow a normal distribution around a mean of 7.694. The degree of habit persistence – being bounded between zero and unity – is assumed to follow a beta distribution around 0.65. The Calvo price-setting parameters (θ's) as well as those governing backward indexation (κ's) are also bounded to lie between zero and one and are assumed to follow beta distributions. Moreover, the prior means for the Calvo parameters reflect the view that South African inflation is fairly sticky, such that domestic prices are re-optimised once every 3 to 4 quarters. Moreover, the firms that do not reset are assumed to place an equal weight on the previous period's inflation rate and the current inflation target. The elasticity of the risk premium in the UIP condition is assumed to follow an inverse-gamma distribution around a mean of 0.01, which equals Alpanda et al.'s 2010 calibration of this parameter. Given the lack of prior information on ϕ_s – the parameter that guides the expected exchange rate modification in the UIP condition – it is assumed to follow a uniform distribution and hence, may take any value between zero and one.

Following Smets and Wouters (2003), the priors for the Taylor rule parameters are fairly standard. However, a larger weight is placed on both output parameters in order to allow for a more flexible approach to inflation targeting, especially during the period following the global financial crisis of 2008.

The persistence of structural shocks are all assumed to follow a beta distribution around a mean of 0.75 with standard deviation of 0.1, while the standard deviations of the shocks themselves are assumed to follow inverse-gamma distributions around means that are more or less in line with Adolfson et al. (2007). However, the risk premium shock allows for a larger standard deviation, largely due to South Africa's emerging market status and the consequent exposure of the Rand to bouts of global risk aversion.

3.5 Posterior estimates

The posterior estimation results are summarised in Table (3), while Figure (**??**) in the Appendix contains the prior and posterior distributions. From the posterior results it can firstly be seen that investment adjustment costs are substantially higher than the prior mean, which implies an elasticity of investment of around 0.1 to a one per cent change in the price of installed capital. At 0.828, the degree of habit formation is found to be higher than Adolfson et al. (2007), but in-line with the estimate of Jääskelä and Nimark (2011) for Australia.

[11] Using the total domestic marketable bonds of the South African government as an off-model proxy for bond supply, the magnitude of the prior mean for the standard deviation of the bond supply shock is loosely guided by the OLS residual standard error of an AR(1) process for this time-series.

The Calvo parameter estimates indicate that import and export price contracts are generally reoptimised every 4 quarters, while domestic contracts are reoptimised at a lower frequency. The inflation indexation parameters are all estimated to be around 0.3 or lower, which implies that a higher weight is placed on the current inflation target than on past inflation during indexation. Although the posterior estimate of the risk premium elasticity ϕ_a is lower than its prior, the data nevertheless to some degree favours the endogenous persistence in the risk premium induced by ϕ_s.

Turning to the estimates for Taylor rule parameters, the posterior mean of 0.895 for the degree of interest rate smoothing closely matches Alpanda et al.'s (2010) estimate of 0.916. It appears as if the SARB places a high weight on interest rate stabilisation. In addition, its reaction to the level of the output gap is more pronounced than what is indicated by the prior on this parameter. The parameter on money growth is substantially lower than the prior, which likely indicates the low weight that is placed on potential inflationary signals emanating from growth in money supply.

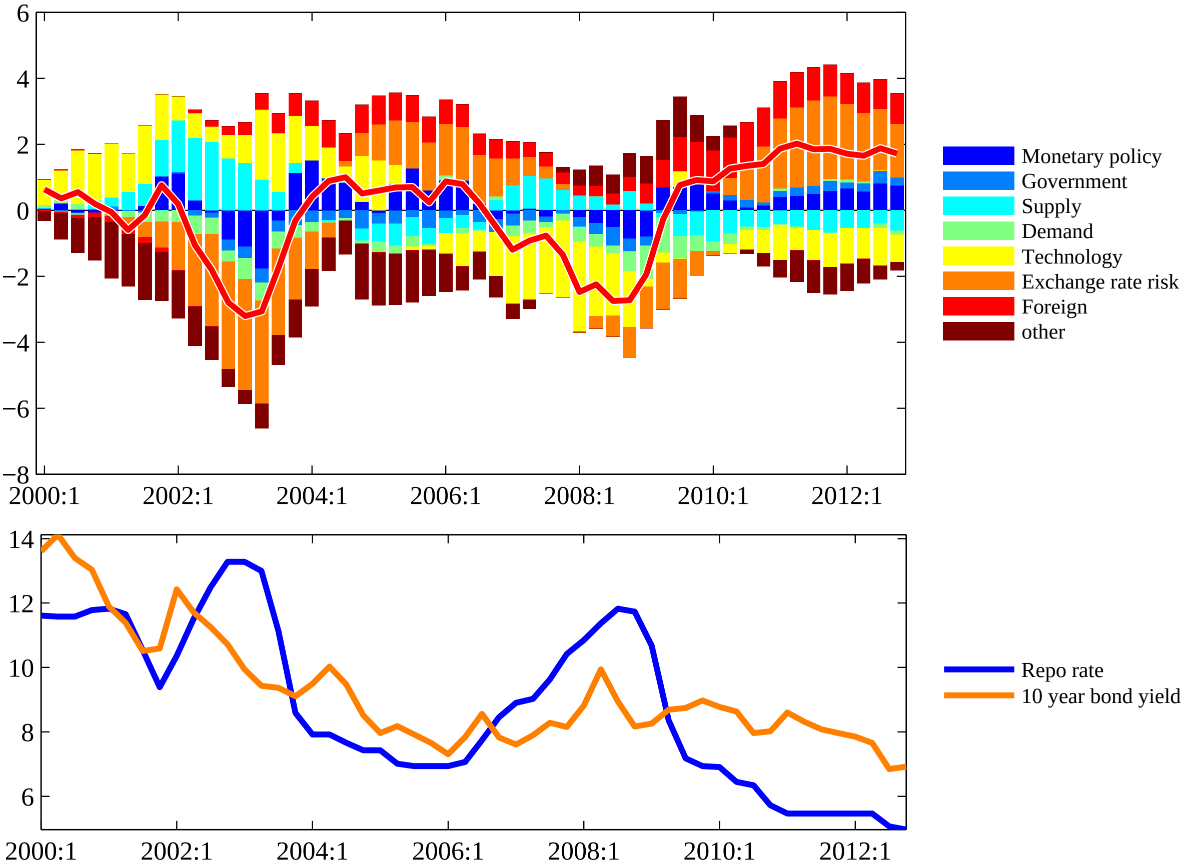
The estimates for the persistence of shocks indicate that consumption and transitory technology shocks are most persistent, while labour and imported consumption markup shocks are least persistent. The standard deviations of the innovations to these shocks vary substantially. Consistent with the heigh weight placed on interest rate stabilisation, monetary policy shocks exhibit low volatility. However, transitory technology and the supply of long-term bonds are the most volatile, with the latter possibly reflecting the volatility of government yields.

4 Historical shock decomposition of the 10 year yield spread

The historical evolution of the unobservable variables of the model, as well as the innovations to the structural shocks may be obtained through the Kalman filter. As such, an analysis of the contributions of these structural shocks to the model's measure of the slope of the yield curve – the spread between the 10 year government bond and the Repo rate – may shed some light on the model's interpretation of its historical evolution. For the sake of visual clarity in Figure 1, certain structural shocks have been grouped, as follows: *Government* represents shocks to government expenditure as well as L-period bond supply; *Supply* consists of domestic price markup shocks as well as imported consumption and investment markup shocks; *Demand* consists of shocks to consumption and investment; *Technology* includes both transitory and permanent technology shocks; and finally, *Foreign* includes shocks to foreign output, inflation and policy shocks.

In the context of the model, the inversion of the yield curve following the depreciation of the Rand in late 2001 was largely driven by exchange rate risk. In addition, the Repo rate was rising during 2002 and 2003, whilst the 10 year yield was declining, hence this policy tightening exacerbated the inversion, as can be seen from the contributions of monetary policy shocks over this period. Nevertheless, the decline in the 10 year yield most likely reflected the financial market's anticipation of future policy easing, which eventually commenced toward the second half of 2003. Hereafter, the positive slope of the yield curve during 2004 and 2005 was once again largely driven by a reduction in exchange rate risk, which kept CPI inflation low and facilitated expansionary monetary policy. At this point in time, global policy interest rates were mostly at very low levels too, which further contributed the steepening of the yield curve.

Figure 1: 10 year government bond yield spread: historical shock decomposition

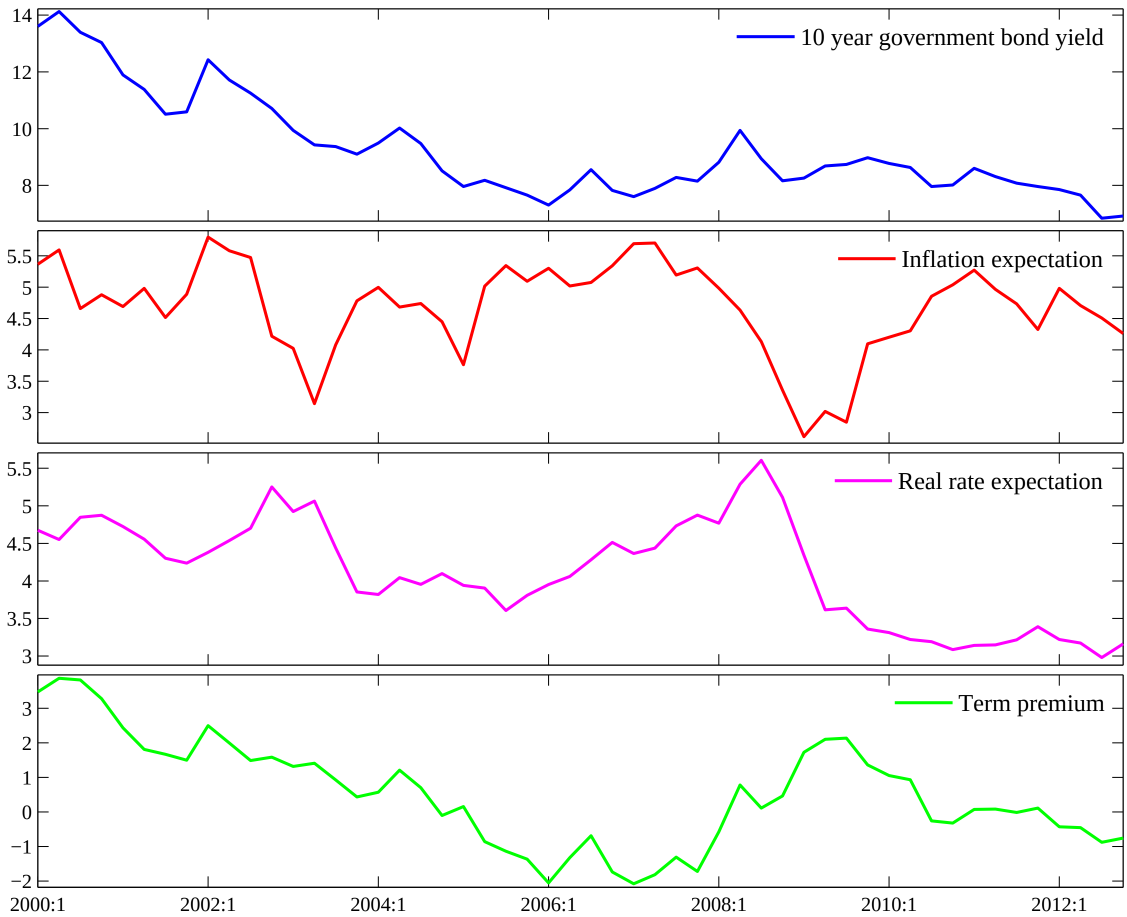


During 2006 and 2007, adverse technology shocks were one of the main contributors to the flattening (and eventual inversion) of the yield curve. In addition, rising international oil prices are reflected by the contribution of supply shocks over this period. At first glance, the positive contribution of these adverse supply shocks seems counter-intuitive. However, it appears as if the significant rise in inflation caused by supply shocks over this period did not only lead to a policy tightening at the short end, but also raised the long end of the yield curve. Hence the net effect entailed a steepening of the curve. At the inversion's peak in 2008Q2 and 2008Q3, monetary policy shocks were one of the main contributors. From the literature's point of view – where an inverted yield curve is associated with a future recession – a slowdown in economic activity was imminent. From late 2008 and onwards, the impact of the global financial crisis and its ensuing recession led to a rapid steepening of the yield curve. In the wake of the financial crisis, the model ascribes this change in direction of the slope to three highly intuitive shocks: monetary policy, global economic conditions and the eventual strengthening of the exchange rate.

5 The expectations hypothesis and the term premium

The rational expectations solution to the structural model allows for a decomposition of the yield on an L-period bond into various *unobserved* components of interest. Firstly, it may be expressed as the sum of an expected yield – as defined by the expectations hypothesis – and a term premium, *i.e.* the

Figure 2: 10 year government bond yield: Expectation components and the term premium



additional compensation investors require to bear the increasing interest rate risk associated with holding the longer-maturity bond. As mentioned before, the expectations hypothesis states that the bond yield of a given maturity reflects a weighted average of expected future short term rates over the period to maturity:

$$R^E_{L,t} = \frac{1}{L} E_t \left[R_t + R_{t+1} + R_{t+2} + \dots + R_{t+L-1} \right] \tag{13}$$

where $R^E_{L,t}$ represents the bond yield that is consistent with the hypothesis. It then follows that for an L-period bond, the deviation in actual bond yields from the level determined by the expectations hypothesis represents the *term premium*, $\zeta^{TP}_{L,t}$:

$$R_{L,t} = R^E_{L,t} + \zeta^{TP}_{L,t}. \tag{14}$$

De Graeve et al. (2009) argue that the rigorous specification of the macroeconomy within a DSGE framework allows for a more rigorous modelling of the formation of expectations, as opposed to competing macro-finance models.

Secondly, Equation (13) may be expressed in Fisher-equation form:

$$R^E_{L,t} = \frac{1}{L} E_t \left[(r_t + \pi^c_{t+1}) + (r_{t+1} + \pi^c_{t+2}) + \ldots + (r_{t+L-1} + \pi^c_{t+L}) \right], \tag{15}$$

where r_t is the real interest rate. This formulation facilitates the decomposition of the yield on an L-period bond into three components: (1) a real interest rate expectation, (2) an expectation of inflation over the life of the bond, and (3) the term premium:

$$R_{L,t} = \frac{1}{L} \sum_{j=0}^{L-1} E_t r_{t+j} + \frac{1}{L} \sum_{j=0}^{L-1} E_t \pi^c_{t+j+1} + \zeta^{TP}_{L,t} \tag{16}$$

By applying Equation (5) to the South African 10 year yield on Government bonds, Figure 2 shows its decomposition into an expected inflation and real interest rate component as well as the term premium. After having largely fluctuated within the upper half of the inflation target band, 10-year inflation expectations briefly fell to below 3 per cent at the height of the global recession in early 2009. Since then it has risen toward the 5 per cent level. Similarly, real interest rate expectations fell from a pre-crisis average of between 4 and 5 per cent to its current level of around 3 per cent. These two components add up to the expected 10 year Repo rate average, and hence their levels toward the end of the sample point to an average Repo rate expectation of between $7\frac{1}{2}$ and 8 per cent.

Finally, the bottom panel in Figure 2 indicates that the model-implied term premium declined throughout the first seven years of the inflation targeting regime. This declining trend implies that holders of 10 year government bonds required less compensation for the risk associated with holding these longer term bonds as opposed to short term securities. However, from late 2007 – the build-up to the financial crisis – the term premium started rising again, and eventually peaked in mid 2009. This pattern largely corroborates with Bernanke's (2006) view that the term premium is inversely related with expected future economic activity. As such, a declining term premium would indicate improving economic activity and *vice versa*.

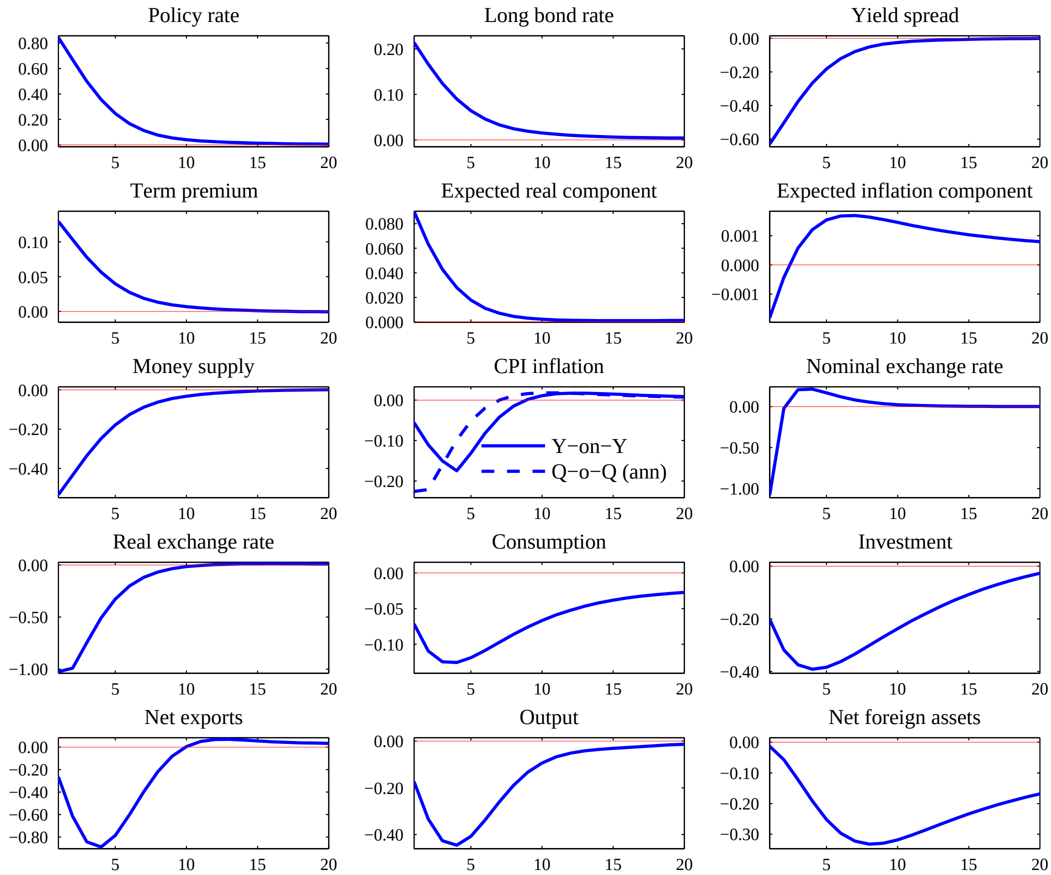
6 Comparative dynamics

In order to analyse the dynamic reaction of the model, but more specifically the yield curve and its various sub-components, we discuss the impulse responses following an increase in the Repo rate, higher government spending and a temporary improvement in technology.

6.1 Monetary policy

A 100 basis point shock to the Taylor rule raises the Repo rate by 85 basis points and the long bond rate by approximately 21 basis points on impact. Consequently, the yield spread narrows by the difference of these two impacts. Regarding the sub-components, both the term premium and expected L-period real interest rate increase, while the reaction of the expected inflation component is almost negligible. Nevertheless, expected inflation initially falls, but increases as CPI inflation is foreseen to overshoot

Figure 3: Monetary policy shock



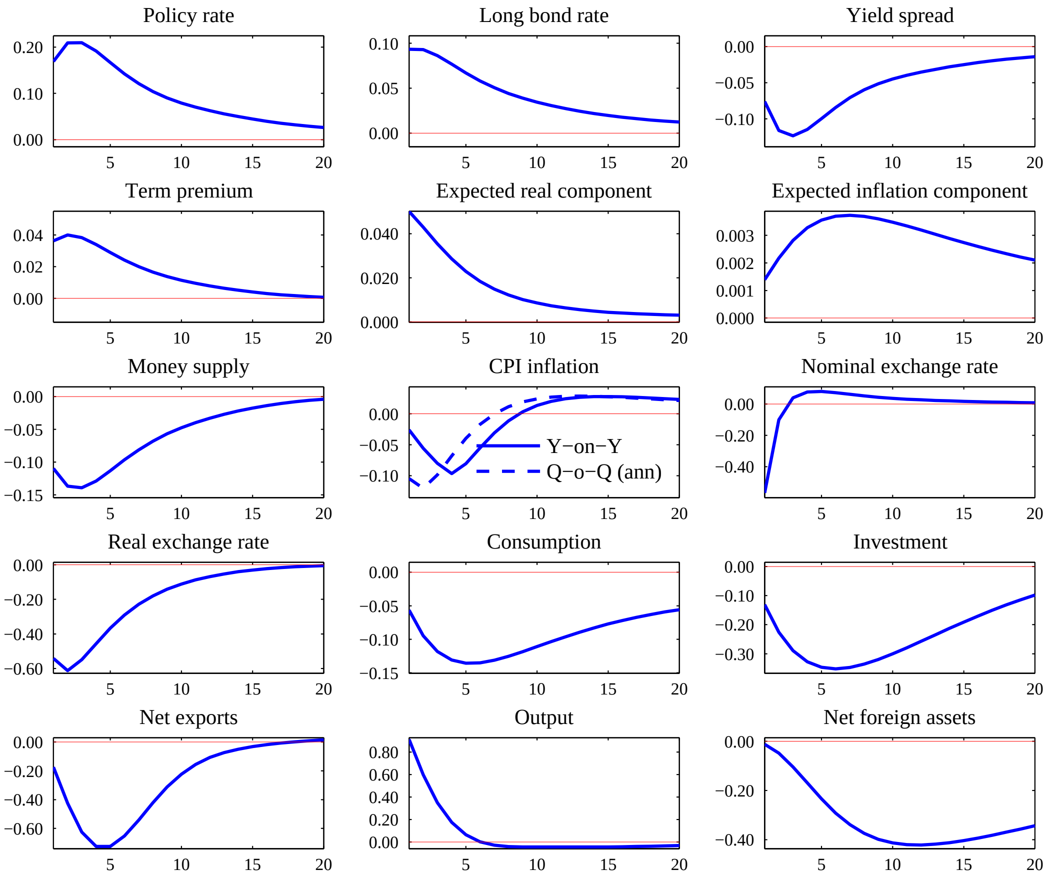
in the medium to longer term. Similar to (Andrés et al., 2004) a liquidity effect is evident as money holdings and interest rates move in opposite directions.

The dynamic reaction of the remaining macroeconomic variables is as expected. CPI inflation falls, with the year-on-year rate peaking at around -0.18 per cent after four quarters. Both the nominal and real exchange rate appreciate, domestic demand falls, as does net exports (in response to the stronger currency). Ultimately output declines to a low in excess of -0.4 per cent after four quarters, and the net foreign asset position of the economy deteriorates.

6.2 Government spending

A 5 per cent increase in government spending increases interest rates across the spectrum and reduces the yield spread. Almost half of the rise in the long bond rate is driven by the increase in the term premium. In addition, both the expected real interest rate and inflation components of the bond yield increase, while the higher interest rates induce a decline in the holdings of money. Moreover, in response to the higher interest rates, consumption falls and investment is crowded out, which in turn reduce inflation. Hence, the rise in output of almost 1 per cent is a direct effect of the increased government spending, which accounts for almost 20 per cent of GDP.

Figure 4: Government spending shock



6.3 Technology

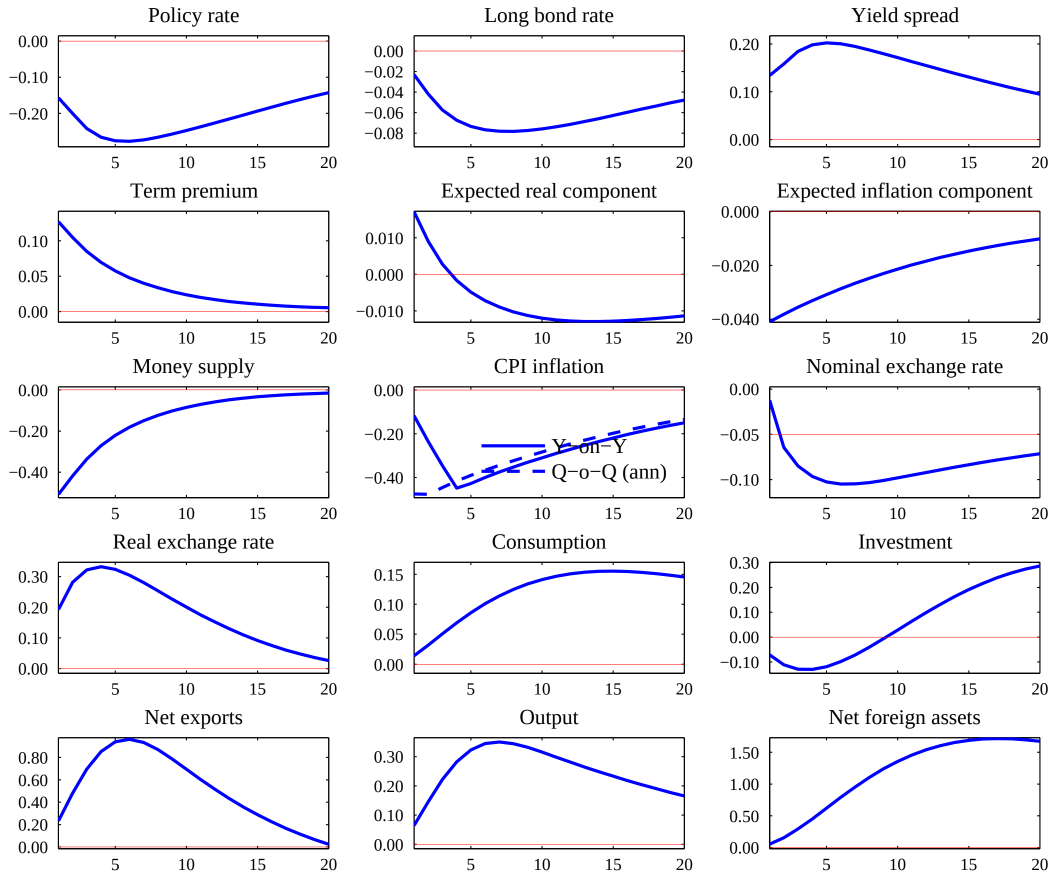
A 1 per cent improvement in transitory technology reduces the Repo rate as inflation falls while output increases. The long bond rate also declines, but to a lesser extent than the Repo rate, which steepens the yield curve. Both expected real interest rates and inflation decline as a result of the lowering of interest rates and inflation. Money holdings decline, as the liquidity effect is most likely counteracted by the impact of lower inflation. The wealth effect brought about by the improvement in technology induces an increase in consumption, at the expense of lower investment. Both net exports and the net foreign asset position benefit from the depreciated real exchange rate, and ultimately the increase in output peaks at 0.4 per cent after 7 quarters.

7 Forecasting the yield curve

Forecasts of interest rates at various maturities do not only play a central role in policy formulation at central banks, but they are also used extensively in the private sector by large corporations and financial institutions, where the yield curve serves as a key input in the pricing of assets and the calculation reference rates for interbank lending, amongst others.

Against this background, the yield-curve extended DSGE model's value as a tool to forecast the South African 10 year government bond rate is assessed by comparing its forecasts to the Reuters poll

Figure 5: Transitory technology shock



of professional forecasters over the period 2006Q1 to 2012Q3. To this end, the model is re-estimated recursively every four quarters – once per year – where the first recursive estimation spans the sample 1993Q1 to 2005Q4, and the last is from 1999Q1 to 2011Q4. The model is then forecast 7 quarters ahead at each quarter.[12] Since the actual observations end in 2012Q4, there are 28 one-quarter-ahead and 22 seven-quarter-ahead forecast errors.

Accordingly, when these forecast errors from the yield-curve DSGE model (DSGE-Y hereafter) are compared to the corresponding errors of the Reuters consensus poll in Table 4, the relative RMSE statistics indicate that professional forecasts of the 10 year government bond yield are superior at the one-quarter horizon. However, from the second quarter onwards, the DSGE-Y model outperforms the Reuters poll.

Given the model's ability to compete with professional forecasts of the 10 year government bond yield, a natural extension of this forecasting exercise would be to establish whether the inclusion of long term bonds in the DSGE model structure affects the model's already established ability to forecast CPI inflation, GDP and the Repo rate. Hence, the remaining rows in Table 4 compare RMSE statistics of the DSGE-Y model's forecasts of these three macroeconomic variables to both the DSGE model developed in Chapter 1, as well as to professional forecasts polled by Reuters. When comparing the CPI inflation forecasts (year-on-year), the results are mixed. Although the DSGE-Y model is superior to Reuters

[12] The Reuters poll of consensus forecasts covers a seven quarter horizon.

Table 4: Forecasting performance of DSGE model with yield curve extension

Relative RMSE statistics	Quarters ahead 1	2	3	4	5	6	7
10 government bond yield							
DSGE-Y / Reuters	1.5690	**0.9879**	**0.9023**	**0.9941**	**0.9135**	**0.7883**	**0.7462**
CPI inflation, year-on-year							
DSGE / Reuters	1.549	1.066	**0.980**	1.029	**0.913**	**0.798**	**0.704**
DSGE-Y / Reuters	1.934	1.208	1.023	1.012	**0.879**	**0.832**	**0.827**
DSGE-Y / DSGE	1.248	1.133	1.043	**0.984**	**0.963**	1.043	1.176
GDP growth (quarter-on-quarter, annualised)							
DSGE / Reuters	1.520	1.528	1.200	1.078	1.012	**0.991**	**0.945**
DSGE-Y / Reuters	1.413	1.205	**0.929**	**0.892**	**0.871**	**0.914**	**0.847**
DSGE-Y / DSGE	**0.929**	**0.789**	**0.774**	**0.827**	**0.861**	**0.922**	**0.897**
Repo rate							
DSGE / Reuters	3.203	2.092	1.447	1.253	1.166	1.096	1.052
DSGE-Y / Reuters	3.049	1.882	1.312	1.137	1.066	1.039	1.071
DSGE-Y / DSGE	**0.952**	**0.900**	**0.906**	**0.907**	**0.914**	**0.947**	1.019

forecasts after 4 quarters, when compared to the DSGE model of Chapter 1, the DSGE-Y model still fares worse over the first three quarters of the forecasting horizon, as well as at quarters 6 and 7. GDP growth forecasts (quarter-on-quarter, annualised) from the DSGE-Y model outperform the Reuters poll of professional forecasters after 2 quarters, while the DSGE model in Chapter 1 was only superior to the Reuters poll at quarters 6 and 7 of the forecast horizon. When the GDP growth forecasts of the DSGE-Y model are compared the model of Chapter 1, the DSGE-Y model is superior at all 7 forecast horizons. Finally, when comparing the models' forecasts of the Repo rate, neither the model from Chapter 1 or the DSGE-Y are able to improve on the Reuters forecasts. Nevertheless, a direct comparison between the two models indicates that Repo rate forecasts from the DSGE-Y model are superior over the first six quarters of the forecast horizon.

8 Do the yield spread and term premium predict future GDP growth

During the last three decades an immense body of literature has developed around this central question: does the term spread predict changes in economic activity?[13] Some have focused on the term spread's ability to forecast output growth, and even more have estimated its ability to predict actual turning points in the business cycle, more specifically recessions. Nevertheless, the consensus result has been convincing: it does.

A number of studies that have considered the capacity of the yield spread in predicting output growth – such as Estrella and Hardouvelis (1991), Estrella and Mishkin (1997) and Haubrich et al. (1996) – have

[13] See Wheelock and Wohar (2009) for a comprehensive survey.

largely used the following specification:

$$\ln(Y_{t+4} - Y_t) \quad = \quad \alpha_0 + \alpha_1 \ln(Y_t - Y_{t-4}) + \alpha_2(R_{L,t} - R_t) + \varepsilon_t, \tag{17}$$

where $\ln(Y_{t+4} - Y_t)$ is the year-on-year change in GDP, four quarters ahead, and $R_{L,t} - R_t$ is the yield spread, i.e., the current difference between the long and short rate. Generally, α_2 is found to be both significant and positive, leading to the inference that an upward-sloping yield curve precedes improved economic growth, while an inverted yield curve tends to be followed by an economic slowdown.

However, since the long-term rate also includes a term premium, movements in the yield spread may originate from either changes in expected future short-term rates, or a changing term premium. This becomes clear when rewriting Equation (14) in terms of the yield spread:

$$R_{L,t} - R_t = \left(R^E_{L,t} - R_t\right) + \zeta^{TP}_{L,t}. \tag{18}$$

Whether or not the term premium in itself contains any predictive ability with respect to GDP, its sign has been a contentious issue. A case in point would be Greenspan's (2005) famous bond yield "conundrum". From June 2004 to February 2005, the Federal Open Market Committee (FOMC) had increased the federal funds rate by 150 basis points, while United States 10 year government bond yields remained almost unchanged over this period. This sideways trend in US 10 year government bond yields continued throughout the eventual 425 basis points increase in the federal funds rate. It was later believed that a declining term premium was the culprit in the conundrum, masking the increase in expected future short rates that would have followed the rising federal funds rate under normal circumstances. Bernanke (2006) contended that the impact of a declining term premium would be "stimulative", and as such, from a practitioner's point of view its coefficient should exhibit a negative sign with respect to economic activity. One of the first studies that investigated the individual predictive ability of term premium was Hamilton and Kim (2002). The authors achieved this by substituting Equation (18)'s expression for the yield spread into Equation (17), as follows:

$$\ln(Y_{t+4} - Y_t) = \alpha_0 + \alpha_1 \ln(Y_t - Y_{t-4}) + \alpha_2(R^E_{L,t} - R_t) + \alpha_3 \zeta^{TP}_{L,t} + \varepsilon_t, \tag{19}$$

where $\alpha_2 = \alpha_3$. By allowing $\alpha_2 \neq \alpha_3$, it then becomes possible to test the individual predictive power of each of the two subcomponents of the yield spread. Hamilton and Kim (2002) find that both α_2 and α_3 are statistically significant and positive. Hence, Bernanke's (2006) view that a declining term premium would stimulate economic activity contradicted Hamilton and Kim's (2002) finding of a positive α_3. Moreover, to intensify the lack of consensus, Ang et al. (2006) also isolated the term premium, but found that it does not bear any predictive power in the context of Equation (19).

A slightly different approach is taken by Rudebusch et al. (2007). The authors argue that the term premium is nearly nonstationary. As such, by respecifying Equation (19) in terms of differences, as follows:

$$\ln(Y_{t+4} - Y_t) = \alpha_0 + \alpha_1 \ln(Y_t - Y_{t-4}) + \alpha_2 \left[(R^E_{L,t} - R_t) - (R^E_{L,t-4} - R_{t-4})\right] + \alpha_3 \left(\zeta^{TP}_{L,t} - \zeta^{TP}_{L,t-4}\right) + \varepsilon_t, \tag{20}$$

(21)

they find that the change in the term premium does predict future economic activity. In addition, α_3 is found to be negative, which adds credence to the view of Bernanke (2006) that the declining term premium in the US would stimulate economic activity.

Given that the South African literature has to date largely focused on the predictive ability of the aggregate yield spread and not its sub-components, having derived a measure of the term premium in the South African 10 year government bond yield makes it a natural extension to test whether these results for the US term premium also hold for the South African economy. Table (5) contains the estimated coefficients for Equations (17), (19) and (20) in columns (1) and (2) and (3), respectively. From column (1) it is evident that – as has been proven before – the standard result holds: the South African yield spread is positively correlated with future economic activity. Column (2), which contains the estimated coefficients for the subcomponents of the yield spread, mirrors the findings of both Ang et al. (2006) and Rudebusch et al. (2007) for the US: the *level* of the South African term premium has no predictive power. However, when the *change* in the term premium is considered, it is found to be a significant predictor of future output, and its negative sign accords with the view of Bernanke (2006) and the finding of Rudebusch et al. (2007).

Table 5: Predictive power of the term spread

	(1)	(2)	(3)
$\ln(Y_t - Y_{t-4})$	0.2 [2.03]**	-0.08 [-0.79]	0.10 [0.67]
$R_{L,t} - R_t$	0.38 [2.05]**		
$R^E_{L,t} - R_t$		0.48 [2.33]**	
$\zeta^{TP}_{L,t}$		-0.16 [-0.95]	
$(R^E_{L,t} - R_t) - (R^E_{L,t-4} - R_{t-4})$			0.30 [4.54]***
$\zeta^{TP}_{L,t} - \zeta^{TP}_{L,t-4}$			-0.67 [-2.51]**

[a]

The coefficient's corresponding Newey-West t-statistics are reported in parentheses, where *,** and *** indicate 90, 95 and 99 per cent confidence intervals.

9 Conclusion

The rational expectations solution to New Keynesian DSGE model provide a credible and consistent characterisation of the expectations formation process - a key component of yield curve dynamics. Moreover, the theoretical rigour of these models have also made them a highly desirable tool with which to analyse the macroeconomic dynamics that are driving developments in the yield curve. As a result, this paper extended the standard New Keynesian DSGE model framework to incorporate long-term government bond yields, in order to analyse the macroeconomic forces that have shaped the yield spread between South African 10 year government bonds and the Repo rate during over the inflation targeting regime of the SARB. Shocks to the exchange rate, technology and monetary policy were found to be some of the key drivers of yield curve dynamics over this period. In addition, the model's forecasts of the 10 year government yield are compared to a Reuters poll of professional forecasters and found to be superior after the one quarter forecast horizon. Finally, the model allows for a decomposition of the yield spread into an expected component and a term premium. This decomposition facilitates the investigation of the predictive power of the individual subcomponents of the yield spread with respect to future economic activity. Although the sign and significance of the term premium's predictive ability has been contentious, changes in the term premium are found to be a significant predictor of future economic activity in South Africa.

References

Adolfson, M., S. Laseén, J. Lindé, and M. Villani (2007). Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics 72*(2), 481–511.

Alpanda, S., K. Kotze, and G. Woglom (2010). Should central banks of small open economies respond to exchange rate fluctuations? the case of South Africa. *Economic Research Southern Africa* (174).

Altig, D., L. Christiano, M. Eichenbaum, and J. Lindé (2011). Firm-specific capital, nominal rigidities and the business cycle. *Review of Economic Dynamics 14*(2), 225–247.

An, S. and F. Schorfheide (2007). Bayesian analysis of DSGE models. *Econometric Reviews 26*(2–4), 113–172.

Andrés, J., J. D. López-Salido, and E. Nelson (2004). Tobin's imperfect asset substitution in optimizing general equilibrium. *Journal of Money, Credit and Banking 36*(4), 665–690.

Andrle, M. (2010). A note on identification patterns in DSGE models. *European Central Bank Working Paper* (1245).

Ang, A. and M. Piazzesi (2003). A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *Journal of Monetary economics 50*(4), 745–787.

Ang, A., M. Piazzesi, and M. Wei (2006). What does the yield curve tell us about gdp growth? *Journal of Econometrics 131*(1), 359–403.

Bekaert, G., S. Cho, and A. Moreno (2010). New keynesian macroeconomics and the term structure. *Journal of Money, Credit and Banking 42*(1), 33–62.

Bernanke, B. S. (2002). Deflation: making sure 'it' doesn't happen here. Presented before the National Economists Club, Washington, DC, 21 November.

Bernanke, B. S. (2006). Reflections on the yield curve and monetary policy. Presented before the Economic Club of New York, 20 March.

Bonga-Bonga, L. (2010). Monetary policy and long-term interest rates in South Africa. *International Business & Economics Research Journal 9*(10).

Cox, J. C., J. E. Ingersoll Jr, and S. A. Ross (1985). A theory of the term structure of interest rates. *Econometrica: Journal of the Econometric Society*, 385–407.

De Graeve, F., M. Emiris, and R. Wouters (2009). A structural decomposition of the us yield curve. *Journal of Monetary Economics 56*(4), 545–559.

Duffie, D. and R. Kan (1996). A yield-factor model of interest rates. *Mathematical finance 6*(4), 379–406.

Ellingsen, T. and U. Söderström (2001). Monetary policy and market interest rates. *American Economic Review*, 1594–1607.

Estrella, A. and G. A. Hardouvelis (1991). The term structure as a predictor of real economic activity. *The Journal of Finance 46*(2), 555–576.

Estrella, A. and F. S. Mishkin (1997). The predictive power of the term structure of interest rates in europe and the united states: Implications for the european central bank. *European Economic Review 41*(7), 1375–1401.

Evans, C. L. and D. A. Marshall (1998). Monetary policy and the term structure of nominal interest rates: Evidence and theory. In *Carnegie-Rochester Conference Series on Public Policy*, Volume 49, pp. 53–111. Elsevier.

Greenspan, A. (2005). Testimony of chairman alan greenspan. In *Federal Reserve Board?s semiannual Monetary Policy Report to the Congress Before the Committee on Banking, Housing, and Urban Affairs, US Senate*, Volume 16.

Hamilton, J. D. and D. H. Kim (2002). A re-examination of the predictability of the yield spread for real economic activity. *Journal of Money, Credit, and Banking 34*(2), 340–360.

Haubrich, J. G., A. M. Dombrosky, et al. (1996). Predicting real growth using the yield curve. *Economic Review 32*, 26–35.

Iskrev, N. (2010a). Evaluating the strength of identification in DSGE models: an a priori approach. *Banco de Portugal Working Paper 201032*.

Iskrev, N. (2010b). Local identification in DSGE models. *Journal of Monetary Economics 57*(2), 189–202.

Jääskelä, J. P. and K. Nimark (2011). A medium-scale New Keynesian open economy model of Australia. *The Economic Record 87*(276), 11–36.

Kessel, R. A. (1965). The cyclical behavior of the term structure of interest rates. *National Bureau of Economic Research Occasional Papers 91*.

Khomo, M. M. and M. J. Aziakpono (2007). Forecasting recession in south africa: a comparison of the yield curve and other economic indicators. *South African Journal of Economics 75*(2), 194–212.

Leeper, E. M. (1991). Equilibria under ‘active’ and ‘passive’ monetary and fiscal policies. *Journal of Monetary Economics 27*(1), 129–147.

Lubik, T. and F. Schorfheide (2005). A bayesian look at new open economy macroeconomics. *NBER Macroeconomics Annual 20*, 313–382.

Martínez-García, E., D. Vilán, and M. A. Wynne (2012). Bayesian estimation of NOEM models: Identification and inference in small samples. *Advances in Econometrics 28*, 137–199.

Marzo, M., U. Söderström, and P. Zagaglia (2008). The term structure of interest rates and the monetary transmission mechanism. *Unpublished manuscript*.

Mishkin, F. S. (2007). *The economics of money, banking, and financial markets*. Pearson education.

Mitchell, W. C. (1913). Business cycles. *University of California Press*.

Moolman, E. (2002). The term structure as a predictor of recessions. *The Journal of Studies in Economics and Econometrics 26*(3).

Nel, H. (1996). The term structure of interest rates and economic activity in South Africa. *The South African Journal of Economics 64*(3).

Nelson, C. R. and A. F. Siegel (1987). Parsimonious modeling of yield curves. *Journal of business*, 473–489.

Rudebusch, G. D., B. P. Sack, and E. T. Swanson (2007). Macroeconomic implications of changes in the term premium. *Federal Reserve Bank of St. Louis Review 89*(4), 241–69.

Rudebusch, G. D. and E. T. Swanson (2012). The bond premium in a dsge model with long-run real and nominal. *American Economic Journal: Macroeconomics 4*(1), 105–143.

Sims, C. A. (2008). Improving monetary policy models. *Journal of Economic Dynamics and Control 38*(2), 2460–2475.

Smets, F. and R. Wouters (2003). An estimated dynamic stochastic general equilibrium model of the Euro area. *Journal of the European Economic Association 1*(5), 1123–1175.

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *The American Economic Review 97*(3), 586–606.

Svensson, L. E. (2000). Open-economy inflation targeting. *Journal of international economics 50*(1), 155–183.

Tobin, J. (1958). Liquidity preference as behavior towards risk. *The Review of Economic Studies*, 65–86.

Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of money, credit and banking 1*(1), 15–29.

Tobin, J. (1982). Money and finance in the macroeconomic process. *Journal of Money, Credit and Banking 14*(2), 171–204.

Vasicek, O. (1977). An equilibrium characterization of the term structure. *Journal of Financial Economics 5*(2), 177–188.

Wheelock, D. C. and M. E. Wohar (2009). Can the term spread predict output growth and recessions? a survey of the literature. *Federal Reserve Bank of St. Louis Review 91*(5), 419–440.

Zagaglia, P. (2009). What drives the term structure in the euro area? evidence from a model with feedback. *Research Papers in Economics 12*.