Monetary Policy, Time-Varying Risk Premiums, and the Economic Content of Bond Yields

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Abstract

The link between the volatility of bond risk premiums and the objective and credibility of monetary policy is explored to understand its implications on bond yield information. A model shows that increased attention to inflation or reduced credibility in the policy increases risk premium volatility. Forward rates and breakeven inflation become less informative about future rates and inflation, respectively. The predictive power of yields declines for inflation, and increases for consumption growth. The model estimation implies high inflation weight and credibility in United States monetary policy. An interpretation of observed changes in yield information based on policy changes is provided.

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1 Introduction

Understanding the economic content of the yield curve has been an important and challenging task for financial economists, macroeconomists, and policymakers. Until recently, most of the analysis of the yield curve had been undertaken assuming that the theory of the expectations hypothesis holds. This theory greatly simplifies the economic interpretation of yield curve movements. For instance, the expectations hypothesis implies that forward rates are unbiased predictors of future interest rates, and expected inflations at different horizons can be obtained as the difference between nominal and real yields of appropriate maturities. Unfortunately, Fama and Bliss (1987) and Campbell and Shiller (1991), among others, present evidence rejecting this theory and shed doubts on the validity of its implications. Dai and Singleton (2002) and Duffee (2002) show that a better description of bond yield dynamics is obtained by allowing for time variation in bond risk premiums. This suggests that understanding the economic information in bond yields requires the analysis of the economic drivers of risk premium variation. Monetary policy, as a determinant of economic performance, may have a significant effect on risk premium properties. This paper analyzes the impact on the economic content of the yield curve of optimal monetary policies that affect time-varying risk premiums.

Term structure studies such as Piazzesi (2005) or Bikbov and Chernov (2008) incorporate monetary policy as an interest rate policy rule. This operational approach is reasonable given the empirical success of the Taylor (1993) rule, but is silent about the underlying policy objectives behind the rule. The current study explores a model that links the objective of monetary policy to economic conditions and the yield curve, while being flexible enough to capture salient bond yield properties.

In the spirit of Clarida, Galí and Gertler (1999), monetary policy has real effects and is conducted to minimize deviations of output and inflation from their targets. The optimality condition for the policy problem provides a restriction involving a tradeoff between inflation and output stabilization. The tradeoff depends on the weight of inflation in the policy objective and the policy credibility. An increase in the inflation weight decreases the volatility of inflation and increases the volatility of output. An increase in policy credibility decreases the volatility of both inflation and output. As a result, changes in the inflation weight and changes in the policy credibility have different effects on the information in the yield curve.

The optimality condition for monetary policy affects bond yields through its effects on the discount factor. Ideally, the discount factor should be linked to the marginal utility of consumption in a fully-fledged general equilibrium framework. However, current equilibrium models impose a strong link between consumption growth and bond yields that is easily rejected in the data. Instead, the discount factor is specified here to depend on the components of inflation and output determined by monetary policy, but also on a latent variable that is not correlated with the policy. This links the dynamics of prices of risk in the discount factor to optimal monetary policy, while providing enough flexibility to fit the data. The discount factor involves compensations for two different shocks: latent factor and supply shocks. The price of these shocks depends on real activity and, then, on the effects of monetary policy on output. Bond risk premiums are compensations for these shocks. Their level, variability, and economic content depend on the policy. The resulting model is then a no-arbitrage term structure model with macroeconomic and latent state variables, as in Ang and Piazzesi (2003), with an additional constraint characterizing the optimal policy.

The model is estimated using data on consumption growth, inflation, and bond yields. It does a reasonable job matching the variability of inflation and yields observed in the data. It also captures the right sign for the deviations from the expectations hypothesis and for predictive regressions of economic variables using bond spreads. The estimation implies a high inflation weight in the policy objective and a high degree of policy credibility. Short-term maturity bonds are more affected by monetary policy than longer term bonds. Bond risk premiums are significant and volatile for all maturities. Monetary policy has important effects on the variability of the prices of risk. An increase in the weight of inflation in the policy increases the volatility of output and then the volatility of the compensations for risk. Bond risk premiums become more volatile, and larger deviations from the expectations hypothesis are observed. An increase in policy credibility has the opposite effect.

Changes in forward rates are the result of changes in expected short-term rates and changes in bond risk premiums. That is, not all variation in forward rates captures changes in expected future rates. The differences between responses to shocks of forward and expected short-term rates are evaluated for different policies. Larger inflation weights in the policy objective tend to increase the difference between these responses. On the other hand, the response differences decrease for policies with higher credibility since bond risk premiums become less volatile. Forward rates then tend to reflect better changes in expected future rates when monetary policy pays less attention to inflation stabilization, or gains credibility.

The difference between nominal and real yields of the same maturity, or breakeven inflation, adjusts to reflect variation in expected inflation or in the compensation for inflation risk in bonds (inflation risk premiums). Similar to the analysis for forward rates, the differences in the response to shocks of breakeven and expected inflations for different policies are also analyzed. These differences capture the effects of monetary policy on inflation risk premiums. While the response of the premium is not very sensitive to the inflation weight in the policy objective, an increase in policy credibility reduces the response of the inflation risk premium to shocks. Therefore, changes in breakeven inflation tend to better reflect changes in inflation expectations if the monetary policy is more credible.

The link between optimal monetary policy and the predictive power of the yield curve is also examined. Spreads between long-term bonds and a short-term rate are used to forecast inflation and consumption growth. The forecast ability can be due to the risk premium component of the spread. Predictive regressions for macroeconomic variables are compared, where the regressor is a bond spread or its expectations hypothesis (EH) component. Differences in these regressions capture the predictive power of bond risk premiums. Predictive regressions for inflation imply negative coefficients on bond spreads and their EH components. The predictive power of the spread (measured by the R^2) decreases with the weight of inflation in the policy objective and increases with the policy credibility. Most of the predictive ability of the spread comes from its EH component. On the other hand, predictive regressions for consumption growth show a significant effect of risk premiums in the predictive power of the curve. Bond risk premiums affect the sign in the predictive power of the spread. The coefficient on the spread is positive and the coefficient on its EH component is negative. Higher weights on inflation stabilization or lower degrees of policy credibility increase the R^2s in predictive regressions of consumption growth.

The analysis concludes with a discussion of potential changes in monetary policy that can explain differences in the join dynamics of the yield curve and macroeconomic variables in different historical periods. We focus on the 1971-1979 inflationary period and the Greenspan era. Larger bond spreads, increased volatility of long-term yields with respect to short-term rates, lower inflation volatility, and a reduced predictive power of inflation during the Greenspan era are consistent with a higher weight on inflation stabilization in the policy. Developments such as smaller deviations from the expectations hypothesis, or a reduced negative correlation between inflation and consumption growth suggest some gains in policy credibility during the same period. However, it is not possible to provide a completely consistent story of changes in bond yields and macroeconomic variables based only on these changes in monetary policy.

Related Literature

The economic content of interest rates has been widely studied from an empirical perspective. Fama and Schwert (1977) explore the hedging properties of bonds against inflation. Harvey (1988) finds that the real term structure forecasts consumption growth. Estrella and Hardouvelis (1991) and Estrella and Mishkin (1998) find that the slope of the yield curve has been successful in predicting recessions. Ang, Piazzesi and Wei (2006) introduce a no-arbitrage framework to the analysis and find that the short-term rate has more predictive power for GDP than any term spread. Their reduced-form approach, however, does not examine the implications of monetary policy on this predictability. Bordo and Haubrich (2004) provide a historical study of the yield curve and monetary policy. They find that the predictive ability of the yield curve is linked to the policy credibility. On a theoretical ground, Estrella (2005) uses an equilibrium model to show that monetary policy can play an important role in the predictability of inflation and output. However, Estrella conducts the analysis in an environment where the expectations hypothesis holds. This paper explores the economic content of yields using a semi-structural term structure model linking monetary policy to macroeconomic variables and yields. Deviations from the expectations hypothesis are captured by time-varying risk premiums that are affected by monetary policy.

The no-arbitrage essentially affine term structure model in the paper is similar to Ang and Piazzesi (2003) or Duffee (2007), which combines macroeconomic and latent variables to explain yield dynamics. However, these papers do not explore the implications of monetary policy on the yield curve. Similar to Hördahl, Tristani and Vestin (2006), Rudebusch and Wu (2008), and Bekaert, Cho and Moreno (2010), this paper estimates a term structure model where monetary policy has real effects. These effects are the result of nominal rigidities as in Woodford (2003). An important difference with these studies is that, instead of modeling monetary policy as an interest rate policy rule, this paper explores optimal policies that result in inflation-targeting rules, as in Palomino (2010). The resulting optimal targeting rule is similar to the one in Gallmeyer, Hollifield and Zin (2005). Important differences with their paper is that in this paper the model is estimated, policy credibility is incorporated, and the analysis has a different focus. While this paper analyzes the economic information in the curve, they focus on providing a structural interpretation to the McCallum (1994) rule. Other papers that analyze the effects of policy rules on the term structure are Piazzesi (2005) or Bikbov and Chernov (2008).

This paper is also linked to the literature that analyzes the economic sources of variation in bond risk premiums. For instance, Brandt and Wang (2003), Cooper and Priestley (2009), and Ang, Dong and Piazzesi (2007) also find that the output gap and/or inflation can be important determinants of bond risk premiums. In this dimension, the paper is also connected to Atkeson and Kehoe (2009), who highlight the importance of incorporating time variation in prices of risk to understand monetary policy.

The paper is organized as follows. Section 2 describes the empirical evidence. Section 3 presents the model for monetary policy and the term structure of interest rates. The model estimation, its analysis, and a brief discussion of its implications are presented in Section 4 and Section 5. Section 6 concludes.

2 Empirical Evidence

This section presents well-known evidence on the economic predictive power of the yield curve and deviations from the theory of the expectations hypothesis.[1] Deviations from the expectations hypothesis can be interpreted as evidence of time-varying expected returns

[1] See Harvey (1988), Estrella and Hardouvelis (1991), and Estrella and Mishkin (1998) for evidence on the predictive power of the yield curve. See Fama and Bliss (1987), Campbell and Shiller (1991), and Cochrane and Piazzesi (2005) for evidence on the rejection of the expectations hypothesis.

in bonds (bond risk premiums). The evidence is presented for different sub-samples that have been associated to different monetary policies. The predictive power of the yield curve and the magnitude of the deviations from the expectations hypothesis are not stable across sub-samples. It suggests a potential link between the predictability of the curve, monetary policy, and time variation in bond risk premiums. This link is explored in Sections 3 and 4.

Quarterly U.S. data from 1971:3 to 2005:4 are used for interest rates, consumption, and consumer prices. The zero-coupon yields for 1- to 10-year bonds are obtained from the Federal Reserve Board database constructed using the Gurkaynak, Sack and Wright (2007) methodology. The short-term nominal interest rate is the 3-month T-bill rate from the Fama risk-free rates database. The consumption growth series was constructed using quarterly data on real per capita consumption of nondurables and services from the Bureau of Economic Analysis. The inflation series was constructed to capture inflation related only to non-durables and services consumption, following the methodology in Piazzesi and Schneider (2007).

The analyzed subperiods correspond to the pre-Volcker era (1971-1979), the Volcker era (1979-1987), and the Greenspan era (1987-2005). The pre-Volcker era covers the early years of the current fiat money regime after the collapse of the Bretton Woods agreement. Clarida, Galí and Gertler (2000) show evidence suggesting a more aggressive response of monetary policy to inflation after 1979.

Panel A in Table 1 reports descriptive statistics for the short-term rate, and the 5- and 10-year bond yields. The average level and slope of the yield curve vary significantly across subperiods. The pre-Volcker era is characterized by low spreads and low volatility in yields in comparison to the 1979-2005 period. The volatilities of the 5- and 10-year bond yield are, respectively, 52% and 47% of the volatility of the short-term rate for the 1971-1979 period. They increase to 88% and 80%, respectively, between 1979 and 2005. Panel A also shows the coefficients for the Campbell and Shiller (1991) regressions associated to bond yields. These regressions are

$$i_{t+1}^{(n-1)} - i_t^{(n)} = \alpha_y + \frac{\beta_y^{(n)}}{n-1}(i_t^{(n)} - i_t) + \varepsilon_{CS,t+1}, \tag{1}$$

where i_t is the 3-month T-bill rate, and $i_t^{(n)} - i_t$ is the spread at time t between the yield of a bond with maturity at $t+n$ and the 3-month T-bill rate. According to the expectations hypothesis, the loadings β_y on the spread should be 1. However, the table shows that these coefficients are negative. Their values and statistical significance vary across sub-samples. The deviations for the period 1971-1979 are larger than those during the Greenspan era.

Panel B in Table 1 presents descriptive statistics for inflation and consumption growth. There are significant differences across subperiods. In particular, the Greenspan era is characterized by low inflation, low volatility, and low persistence in inflation and consumption growth, and low negative correlation between inflation and consumption growth in comparison to the other subperiods.

Panel C in Table 1 shows the results of predictive regressions for inflation and consumption growth using the yield curve. Specifically, the predictive regressions for four-quarter ahead inflation (π) and consumption growth (Δc) are

$$mv_{t,t+4} = \alpha_{mv} + \beta_{mv}\,(i_t^{(n)} - i_t) + \varepsilon_{mv,t+4}, \tag{2}$$

where $mv = \{\Delta c, \pi\}$. The table shows results for regressions where the 5- or 10-year bond spreads are used. The regressions for the four-quarter ahead inflation show significant negative loadings on the spreads, but the magnitude and significance of the loadings vary across sub-samples. In particular, the significance of the loadings and R^2s of the regressions for the Greenspan era are lower than for the other sub-samples. The regressions for the four-quarter ahead consumption growth also show significant differences across periods. The loadings on the spreads are positive for the whole sample, very high for the period 1971-1979, and not significantly different from zero for the Greenspan era.

The evidence suggests differences in the the predictive power of the term structure across different monetary policy regimes. Differences in the dynamics of consumption and inflation, and time variation in bond risk premiums, may be linked to these differences.

3 The Model

This section presents a model linking economic conditions, monetary policy, and the term structure of interest rates. The basic framework for policy analysis in, for instance, Clarida, Galí and Gertler (1999) or Woodford (2003), is extended to capture salient properties of bond yields and bond risk premiums. The model is used in Section 4 to analyze the economic information embedded in bond yields and its dependence on monetary policy.

3.1 Optimal monetary policy

The monetary policymaker chooses optimal contingent paths for the output gap, x_t, inflation, π_t, and the one-period nominal interest rate, i_t, to minimize a loss function. The output gap can be seen as the component of output that can be affected by monetary policy. In this framework, monetary policy affects output as a result of nominal price rigidities in the production sector. The output gap is then the difference between actual output and the output that would be observed if prices were perfectly flexible.

The policymaker wants to minimize the loss function

$$\mathbb{E}\left\{\sum_{t=0}^{\infty}\beta^t\left[\rho(\pi_t-\pi^*)^2+\kappa x_t^2\right]\right\} \tag{3}$$

subject to

$$e^{-i_t} \;=\; \mathbb{E}_t\left[M_{t,t+1}\right], \tag{4}$$

and

$$\pi_t-\pi^*=\kappa x_t+\beta\mathbb{E}_t\left[\pi_{t+1}-\pi^*\right]+u_t. \tag{5}$$

The policy objective (3) can be seen as a welfare measure where deviations of output from the flexible price output (output gap), or deviations of inflation from a target π^*, reduce welfare. The parameter β is a subjective discount factor, and ρ and κ are the relative weights assigned to inflation and output deviations, respectively. Rotemberg and Woodford (1999) show that the objective function can be obtained from a quadratic approximation of a particular households' utility function. The objective function is not linked here to the households' utility. This flexibility allows examination of policies where the monetary authority is more or less conservative about inflation than what the utility-based welfare criterion prescribes.

The policymaker is constrained by conditions characterizing the optimal behavior of the private sector (households and firms). Equation (4) is the optimality condition for the households' problem relating the price of a one-period nominal bond to the one-period nominal discount factor, $M_{t,t+1}$. The specification of the discount factor presented below plays a fundamental role in capturing bond yield properties. Equation (5) describes the optimality condition for the profit maximization problem in the production sector.[2] Nominal price rigidities generate a link between inflation, the output gap, and expected future inflation. The inflation sensitivity to the output gap is captured by the parameter $\kappa > 0$. Higher degrees of price rigidity are associated with lower values of κ. The dependence on future expected inflation is the result of the forward-looking nature of the production problem. The last term in the equation is the cost-push shock u_t. It can be interpreted as a markup shock or, more general, as a deviation breaking the proportionality between marginal cost deviations and the output gap. For simplicity, this shock is referred to as a supply shock. It follows the process

$$u_{t+1} = \phi_u u_t + \sigma_u \varepsilon_{u,t+1}, \tag{6}$$

where $\varepsilon_{u,t} \sim \text{IID}\mathcal{N}(0,1)$. This shock generates time variation in inflation and a non-zero correlation between output and inflation.

The policymaker solves the policy problem in an environment where the degree of policy credibility is $\delta \in [0,1]$. We capture credibility as the probability that the policy affects private agents' expectations. It covers the extreme cases of discretion ($\delta = 0$), where expectations of the private sector are taken as given, and perfect commitment ($\delta = 1$). Under this assumption, Appendix A shows that the optimality condition for the problem above becomes[3]

$$-\rho(\pi_t - \pi^*) = x_t - \delta x_{t-1}. \tag{7}$$

This equation can be seen as a targeting rule for inflation. It indicates that the optimal policy involves a tradeoff between inflation and current and lagged output gaps. The exact

[2] The microfoundations and derivation of this equation can be found, for instance, in Woodford (2003).

[3] Notice that the short-term interest rate equation (4) does not play a role in determining this optimality condition since the objective function does not depend on this interest rate.

tradeoff depends on the relative weight of inflation in the policy objective, ρ, and the degree of policy credibility, δ. A higher inflation weight allows more deviations in output with respect to the target. The degree of credibility determines the importance of the lagged output gap in the tradeoff. Under perfect discretion, inflation is proportional to the output gap. Under perfect commitment, inflation is proportional to changes in the output gap.

From the optimality condition above and equation (5), it can be shown that the endogenous process for the output gap is

$$x_t = \phi_x x_{t-1} + \phi_{x,u} u_t, \tag{8}$$

where

$$\phi_x = \frac{1 + \kappa\rho + \beta\delta - \sqrt{(1 + \kappa\rho + \beta\delta)^2 - 4\beta\delta}}{2\beta}, \quad \text{and} \quad \phi_{x,u} = -\frac{\rho}{1 + \kappa\rho - \beta\phi_u + \beta(\delta - \phi_x)}.$$

The endogenous process for inflation can be written as the ARMA(1,1) process

$$\pi_t - \pi^* = \phi_x(\pi_{t-1} - \pi^*) - \frac{\phi_{x,u}}{\rho}(u_t - \delta u_{t-1}). \tag{9}$$

It is clear that the sensitivity of inflation to supply shocks depend on the policy parameters ρ and δ.

The one-period nominal interest rate is obtained from equation (4), once we characterize the dependence of the nominal discount factor $M_{t,t+1}$ on output and inflation. This interest rate can be used as the instrument for the implementation of monetary policy. The dependence of the equilibrium interest rate on economic conditions can be seen as a policy rule, where the reaction to the state of the economy depends on the inflation weight and the credibility of the policy.

3.2 The nominal discount factor

It is desirable to obtain the discount factor from a completely specified equilibrium model for the analysis of monetary policy, as in Woodford (2003). Unfortunately, the available models impose a very strong link between bond prices and consumption growth that is easily rejected in term structure models.[4] Empirical analysis such as Ang and Piazzesi (2003) have shown that macroeconomic variables help to capture some of the variability of bond yields. However, there is a significant variability that has to be explained by latent variables with no clear economic interpretation. Thus, it is specified a "reduced-form" discount factor that depends on the output gap, inflation, and a latent factor. It captures important properties for bond yields, while providing a link to the monetary policy described above. A potential economic interpretation for this discount factor is that it corresponds to the marginal rate of substitution of consumption of a marginal household with access to the bond market and consumption C_t^*. Additional flexibility in the specification is gained from the fact that consumption C_t^* is not imposed to be aggregate consumption C_t.[5] The process for the household's consumption growth, $\Delta c_t^* = \log C_t^* - \log C_{t-1}^*$, is specified as

$$\Delta c_t^* = z_t + \Delta x_t, \tag{10}$$

[4]See, for instance, Palomino (2010) for a structural New Keynesian model of the term structure. Duffee (2007) shows evidence of the limited ability of macroeconomic variables to explain time variation in bond risk premiums.

[5]Consider, for instance, the limited participation framework in Basak and Cuoco (1998) where the relevant consumption for asset pricing is the stockholders' consumption, or the durable and non-durable consumption framework in Yogo (2006). In these frameworks, the relevant consumption C_t^* is linked to aggregate consumption C_t by $C_t^* = \Omega_t C_t$, for an appropriate process Ω_t. We do not take a stand on the economic interpretation of Ω_t, but allow the data in the estimation to exploit a potential link between C_t^* and C_t.

where

$$z_{t+1} = (1 - \phi_z)\theta_z + \phi_z z_t + \sigma_z \varepsilon_{z,t+1}, \tag{11}$$

with innovations $\varepsilon_{z,t} \sim \text{IID}\mathcal{N}(0,1)$. The latent process z_t is the component of Δc_t^* that is not affected by monetary policy, and $\varepsilon_{z,t}$ is the latent factor shock. The process for aggregate consumption growth, $\Delta c_t \equiv \log C_t - \log C_{t-1}$ can be written as

$$\Delta c_t \equiv \Delta c_t^* + \upsilon_c \epsilon_{c,t}, \tag{12}$$

where $\upsilon_c \epsilon_{c,t}$ is the component of aggregate consumption growth that is not useful to price bonds. This specification will be used in the empirical implementation of the model.

The representation in Gallmeyer, Hollifield and Zin (2005) for the household's utility is used, given by

$$\sum_{t=0}^{\infty} \beta^t \frac{(C_t^*)^{1-\gamma}}{1-\gamma} Q_t.$$

This representation differs from the standard constant relative risk aversion setting in that it incorporates the preference shock Q_t. The process for the shock $q_t \equiv \log Q_t$ depends on the consumption growth for the marginal consumer. It is specified as

$$-\Delta q_{t+1} = \frac{1}{2}(\eta \Delta c_t^*)^2 \text{var}_t\left(\Delta c_{t+1}^*\right) + \eta \Delta c_t^* \left(\Delta c_{t+1}^* - \mathbb{E}_t[\Delta c_{t+1}^*]\right), \tag{13}$$

which allows for risk aversion that changes over time, as in Campbell and Cochrane (1999), or Wachter (2006). The preference shock is driven by the unexpected component $\Delta c_{t+1}^* - \mathbb{E}_t[\Delta c_{t+1}^*]$. The time-varying volatility of the shock depends on lagged household's consumption growth and the sensitivity parameter η. This parameter determines the time variation in bond risk premiums and will be fundamental to capturing the average positive slope of the yield curve. Notice that for $\eta = 0$, and C_t^* equal to aggregate consumption, the specification above reduces to the standard constant relative risk aversion case for the representative agent. The quadratic term in equation (13) on Δc_t^* is a correction term that makes $Q_t = \mathbb{E}_t[Q_{t+1}]$, and conveniently preserves the affine framework for the equilibrium term structure below. The specifications for the preference shock and the process Δc_t^* make the price of risk depend on the output gap. This is consistent with the evidence of predictive power of the output gap for bond returns in Cooper and Priestley (2009). Alternatively, given the link between the output gap and inflation imposed by monetary policy, the price of risk depends on unexpected inflation, as in Brandt and Wang (2003).

The solution to the household's utility maximization problem (taking the shock Q_t as given) provides the intertemporal marginal rate of substitution of consumption between periods t and $t+n$, $M_{t,t+n}$. It is

$$M_{t,t+n} = \beta^n \left(\frac{C_{t+n}^*}{C_t^*}\right)^{-\gamma} \left(\frac{Q_{t+n}}{Q_t}\right) \left(\frac{P_{t+n}}{P_t}\right)^{-1}, \tag{14}$$

where P_t is the nominal price of the consumption good, such that $\pi_t \equiv \log P_t - \log P_{t-1}$. It follows that the price of an n-period default-free bond and its associated continuously compounded bond yield are

$$b_t^{(n)} = \mathbb{E}_t[M_{t,t+n}], \quad \text{and} \quad i_t^{(n)} = -\frac{1}{n} \log b_t^{(n)}, \tag{15}$$

respectively. Constraint (4) in the policy problem can be seen as a particular case of equation (15) when $n = 1$. This equation can be written as

$$e^{-i_t} = \mathbb{E}_t \left[\exp(\log \beta - \gamma \Delta c_{t+1}^* + \Delta q_{t+1} - \pi_{t+1})\right]. \tag{16}$$

That is, the equilibrium one-period interest rate i_t depends on the processes for the household's consumption growth and inflation. The discount factor depends on monetary policy through its dependence on the output gap in equation (10) and inflation.

Notice that there are two shocks in this economy: $\varepsilon_{u,t}$ and $\varepsilon_{z,t}$. The compensation for these two sources of risk embedded in bond yields are characterized below, along with how these compensations depend on monetary policy.

3.3 The term structure of interest rates

Bond yields for different maturities are obtained from the equilibrium equation (15) in terms of preference, production, and policy parameters. Appendix B present a discrete-time Duffie and Kan (1996) affine term-structure model in which equilibrium yields are linear combinations of a set of state variables, with coefficients restricted by no-arbitrage and economic constraints. This representation is useful to understand the link between economic activity, monetary policy, and bond yields.

Consider the set of state variables $\mathbf{s}_t$ following the first-order vector autoregression

$$\mathbf{s}_{t+1} = (\mathbb{I} - \Phi)\theta + \Phi\mathbf{s}_t + \Psi^\top \Sigma^{1/2} \varepsilon_{t+1}, \tag{17}$$

and the one-period stochastic discount factor $M_{t,t+1}$, given by

$$-\log M_{t+1} = \Gamma_0 + \Gamma_1^\top \mathbf{s}_t + \frac{1}{2}\lambda(\mathbf{s}_t)^\top \Psi^\top \Sigma \Psi \lambda(\mathbf{s}_t) + \lambda(\mathbf{s}_t)^\top \Psi^\top \Sigma^{1/2} \varepsilon_{t+1}. \tag{18}$$

The potentially time-varying prices of risk are obtained from the sensitivity to uncertainty in the discount factor as

$$\lambda(\mathbf{s}_t) = \mathbb{A}\left(\lambda_0 + \lambda_1 \mathbf{s}_t\right). \tag{19}$$

From this specification and the bond pricing equation (15), bond yields are

$$i_t^{(n)} = \frac{1}{n}\left[\mathcal{A}_n + \mathcal{B}_n^\top \mathbf{s}_t\right], \tag{20}$$

with coefficients $\mathcal{A}_n$ and $\mathcal{B}_n$ obtained recursively as

$$\begin{aligned}\mathcal{A}_n &= \Gamma_0 + \mathcal{A}_{n-1} + \mathcal{B}_{n-1}^\top\left[(\mathbb{I}-\Phi)\theta - \Sigma_\Psi \mathbb{A}\lambda_0\right] - \frac{1}{2}\mathcal{B}_{n-1}^\top \Sigma_\Psi \mathcal{B}_{n-1},\\ \mathcal{B}_n^\top &= \Gamma_1^\top + \mathcal{B}_{n-1}^\top\left[\Phi - \Sigma_\Psi \mathbb{A}\lambda_1\right],\end{aligned} \tag{21}$$

where $\Sigma_\Psi = \Psi^\top \Sigma \Psi$, and initial conditions $\mathcal{A}_0 = 0$ and $\mathcal{B}_0 = \mathbf{0}$. This is the essentially affine term structure model used in Duffee (2002), Dai and Singleton (2002), or Ang and Piazzesi (2003), for instance. An important difference is that, in addition to the no-arbitrage constraint for yield dynamics, the economic model above imposes additional restrictions. The dynamics of the state variables and the stochastic discount factor are restricted by monetary policy parameters, as shown in Result 1. Three state variables are required to describe the dynamics of the term structure: the latent factor z_t, the supply shock u_t, and the lagged output gap x_{t-1}.

Result 1. *The process for the state variables and the nominal discount factor associated to the model are represented by equations* (17)*,* (18)*, and* (19)*, when*

$$\mathbf{s}_t \equiv (z_t,\ u_t,\ x_{t-1})^\top$$

and

$$\Phi = \begin{bmatrix} \phi_z & 0 & 0 \\ 0 & \phi_u & 0 \\ 0 & \phi_{x,u} & \phi_x \end{bmatrix}, \quad \theta = \begin{pmatrix} \theta_z \\ 0 \\ 0 \end{pmatrix}, \quad \Psi^\top = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix},$$

$$\Sigma^{1/2} = diag\{\sigma_z,\, \sigma_u\}, \qquad \varepsilon = (\varepsilon_z,\, \varepsilon_u)^\top,$$

$$\Gamma_0 = -\log\beta + \pi^* + \gamma(1-\phi_z)\theta_z - \frac{1}{2}\gamma^2\sigma_z^2 - \frac{1}{2}\left(\gamma - \frac{1}{\rho}\right)^2 \phi_{x,u}^2\sigma_u^2,$$

$$\Gamma_1 = \begin{pmatrix} \gamma\phi_z - \eta\mu \\ \phi_{x,u}\left[\left(\gamma - \frac{1}{\rho}\right)(\phi_u + \phi_x) - \gamma + \frac{\delta}{\rho} - \eta\mu\right] \\ -\gamma(1-\phi_x)\phi_x - \frac{\phi_x}{\rho}(\phi_x - \delta) + \eta(1-\phi_x)\mu \end{pmatrix},$$

$$\lambda_0 = \begin{pmatrix} \gamma \\ \left(\gamma - \frac{1}{\rho}\right)\phi_{x,u} \end{pmatrix}, \quad \lambda_1 = \eta \begin{pmatrix} 1 \\ \phi_{x,u} \end{pmatrix} (1, \quad \phi_{x,u}, \quad -(1-\phi_x)), \quad \mathbb{A} = \begin{bmatrix} \mathbb{I}_{2\times 2} \\ \mathbf{0}_{1\times 2} \end{bmatrix},$$

and

$$\mu = \gamma\sigma_z^2 + \phi_{x,u}^2\left(\gamma - \frac{1}{\rho}\right)\sigma_u^2.$$

Proof. Replace equations (8), (10), and (11) in equation (14) for $n = 1$ to express the equilibrium $\log M_{t,t+1}$ in terms of z_t, u_t, and x_t. Obtain the components λ_0 and λ_1 of $\lambda(\mathbf{s}_t)$ in (18) from the stochastic component of the equilibrium discount factor. Compute $\lambda(\mathbf{s}_t)^\top\Psi^\top\Sigma\Psi\lambda(\mathbf{s}_t)$, and subtract those terms in the quadratic form which are not in the equilibrium discount factor, to obtain Γ_0 and Γ_1. □

The relative weight of inflation in the policy objective, ρ, and the degree of credibility, δ, determine the output gap, inflation and, therefore, bond yields. Monetary policy affects the sensitivity of the discount factor to the state variables, Γ_1, and the market prices of risk for the latent factor and supply shocks.

Result 1 also shows that the time-varying components of the market price of risk in λ_1 depend on the parameter η and the policy parameters ρ and δ. The particular case $\eta = 0$ implies a constant price of risk. For $\eta \neq 0$, the price of the two sources of uncertainty depend on economic conditions. The sensitivity to the state of the economy is

$$\lambda_1 \mathbf{s}_t = \eta \begin{pmatrix} 1 \\ \phi_{x,u} \end{pmatrix} \Delta c_t^* = \eta \begin{pmatrix} 1 \\ \phi_{x,u} \end{pmatrix} \left[z_t + \phi_{x,u} u_t - (1-\phi_x) x_{t-1} \right].$$

The dependence of the output gap on inflation generated by the optimal monetary policy, makes the price of risk correlated with inflation. Changes in the policy parameters ρ and δ, are reflected in changes in ϕ_x and $\phi_{x,u}$, which affect the prices of risk related to latent factor shocks, $\varepsilon_{z,t}$, and supply shocks, $\varepsilon_{u,t}$.

The effect of monetary policy on the price of latent factor shocks is entirely driven by the existence of preference shocks ($\eta \neq 0$) with time-varying volatility. The average price of this risk is not affected by the policy, but its time variation depends on the output gap. The price of supply shocks is affected by monetary policy even in the absence of preference shocks, Q_t. The constant component of the market price of supply shocks in λ_0 is $\gamma - \frac{1}{\rho}$. This price of risk can be positive or negative depending on the value of ρ. In addition, $\eta \neq 0$ makes the price of supply shocks depend on both the latent factor and the process for the output gap.

3.4 Time-varying bond risk premiums

Long-term yields can be seen as risk-adjusted expectations of future short-term interest rates. The risk adjustment is constant or zero under the theory of the expectations hypothesis. This theory is convenient to interpret the information of the term structure: Changes in long-term bond yields simply reflect changes in expected future short-term rates. Empirical studies such as Campbell and Shiller (1991) or Fama and Bliss (1987), however, provide evidence of deviations from the expectations hypothesis in the data. This rejection, which can be interpreted as evidence of time-varying bond risk premiums, complicates the analysis of the information in the yield curve. The equilibrium term structure model above implies time variation in bond risk premiums.

Consider the one-period risk premium on an n-period bond, $\mathbb{E}_t\left[xr_{t,t+1}^{(n)}\right]$. It is the one-period expected excess return for holding an n-period bond with respect to the return on a one-period bond. That is,

$$\mathbb{E}_t\left[xr_{t,t+1}^{(n)}\right] = -(n+1)\mathbb{E}_t\left[i_{t+1}^{(n-1)}\right] + ni_t^{(n)} - i_t. \tag{22}$$

This representation for expected excess returns allows the convenient characterization for bond yields,

$$i_t^{(n)} = \frac{1}{n}\mathbb{E}_t\left[\sum_{j=0}^{n-1} i_{t+j}\right] + \frac{1}{n}\mathbb{E}_t\left[\sum_{j=0}^{n-2} xr_{t+j,t+j+1}^{(n-j)}\right], \tag{23}$$

in terms of two components. The first component reflects the pure expectations hypothesis. The second component contains the sum of the one-period expected excess returns embedded in the n-period bond until maturity. Deviations from the expectations hypothesis can be potentially captured if this component is not constant.

The no-arbitrage recursive equations (21) and the bond risk premium equation (22) imply

$$\mathbb{E}_t\left[xr_{t,t+1}^{(n)}\right] \;=\; -\mathcal{B}_{n-1}^{\top}\Sigma_{\Psi}\left(\mathbb{A}\lambda_0 + \frac{1}{2}\mathcal{B}_{n-1}\right) - \mathcal{B}_{n-1}^{\top}\Sigma_{\Psi}\mathbb{A}\lambda_1\mathbf{s}_t. \tag{24}$$

From this equation, a necessary condition for time variation in bond risk premiums is a time-varying market price of risk ($\lambda_1 \neq 0$). The preference shock Q_t, the relative weight assigned to inflation in the policy objective, and the policy credibility are then fundamental to characterize deviations from the expectations hypothesis. To see this, consider the Campbell and Shiller (1991) coefficients, $\beta_y^{(n)}$, in regression (1). Using equation (22), these coefficients can be written as

$$\beta_y^{(n)} = 1 - \frac{\operatorname{cov}\left(i_t^{(n)} - i_t, \mathbb{E}_t\left[xr_{t,t+1}^{(n)}\right]\right)}{\operatorname{var}\left(i_t^{(n)} - i_t\right)},$$

implying that deviations from the expectations hypothesis (deviations from coefficients equal to 1) are potentially captured by the correlation between term spreads and one-period bond risk premiums. In the model, this correlation is different from zero only if preference shocks have time-varying volatility. The magnitude of this correlation is determined by policy parameters.

4 Analysis

This section describes the model estimation strategy, presents the estimation results, and analyzes the implications of changes in the policy parameters on the economic content of the yield curve. The analysis is performed in three different dimensions. First, the relation between forward rates and expectations about future short-term rates. Second, the relation between expected inflation and the difference between nominal and real yields (or breakeven inflation). And third, the predictive power of the yield curve for inflation and consumption growth.

4.1 Estimation

Maximum likelihood estimation is implemented using the Kalman filter. The quarterly data described in Section 2 from 1971:3-2005:4 are used for consumption growth, inflation, the 3-month interest rate, and bonds with annual maturities from 1 to 10 years. The set of observational equations is

$$W_t = \left(\Delta c_t,\, \tilde{\pi}_t,\, \tilde{i}_t,\, \tilde{i}_t^{(4)},\, \tilde{i}_t^{(8)},\, ...,\, \tilde{i}_t^{(40)}\right)^\top = A + B\mathbf{s_t} + \Upsilon\epsilon_t,$$

where the tilde ($\sim$) denotes the observed value for the related variable. The vector of observational errors is $\epsilon_t \sim \text{IID}\mathcal{N}(0, \mathbb{I})$. The vector A and matrix B contain the constants and the loadings of the observed variables on the state variables, respectively. Consumption growth, Δc_t, is linked to Δc_t^* by equation (12). That is, the process for consumption growth is linked to the latent factor and the output gap in equation (10). The coefficients for inflation are restricted by monetary policy according to equations (7) and (8). The coefficients for the short-term rate and bond yields are restricted by the no-arbitrage constraints in equation (21) and the restrictions from the discount factor and monetary policy in result 1. Specifically, the coefficients are

$$A = \begin{pmatrix} 0 \\ \pi^* \\ \mathcal{A}_1 \\ \frac{1}{4}\mathcal{A}_4 \\ \vdots \\ \frac{1}{40}\mathcal{A}_{40} \end{pmatrix}, \quad \text{and} \quad B = \begin{bmatrix} 1 & \phi_{x,u} & -(1-\phi_x) \\ 0 & -\frac{\phi_{x,u}}{\rho} & \frac{(\delta-\phi_x)}{\rho} \\ & \mathcal{B}_1^\top & \\ & \frac{1}{4}\mathcal{B}_4^\top & \\ & \vdots & \\ & \frac{1}{40}\mathcal{B}_{40}^\top & \end{bmatrix}.$$

The matrix $\Upsilon = \text{diag}\{\upsilon_c, \upsilon_\pi, \upsilon_i, \upsilon_y, ..., \upsilon_y\}$ contains the volatilities of the observational errors. That is, the observational errors are assumed to be uncorrelated across observed variables. The error in the process for consumption growth is interpreted as the component of consumption growth that does not affect the discount factor. The error in inflation is interpreted as measurement error, or as a transitory component of inflation that is not spanned by the discount factor, as in Duffee (2007) or Kim (2009). The errors in the 3-month rate and all bond yields are interpreted as measurement error. The volatility of the measurement error for the 3-month rate is υ_i and all bond yields share the same volatility in the error, υ_y.

Table 2 presents the model parameters implied by the estimation. A set of parameters is estimated and another set is calibrated. Five parameters (γ, η, ϕ_z, ρ, δ) and three error volatilities (υ_c, υ_i, υ_y) are estimated. The parameter κ capturing the link between the output gap and inflation is obtained from the macro literature. The parameter β is set to match the average 3-month interest rate. The fact that it is greater than one in the estimation sheds doubts on interpreting it as a subjective discount factor. The inflation target π^* and the parameter θ_z are set to match the average inflation and the average consumption growth, respectively. The parameters ϕ_u and σ_u are restricted to match the first-order autocorrelation and the unconditional volatility of inflation, respectively. The standard errors for the constrained parameters are computed using the delta method. The volatility of the measurement error in inflation, υ_π, is set at 0.001. Attempts to estimate this parameter resulted in a large measurement error in inflation and a bad fit for yields.

The parameter η is positive and significant. This parameter allows the model to obtain an upward sloping curve and time variation in expected excess returns. The value for ρ implies a high weight of inflation in the policy function. It is $\frac{\rho}{\rho+\kappa} = 0.92$. The parameter δ implies a high degree of credibility in the policy (95%). The autocorrelation parameters ϕ_z and ϕ_u imply very persistent processes for the latent factor and the supply shocks. The volatility of the observational error of the 3-month interest rate is significantly higher than the volatility of the observational error for bond yields.

Figure 1 shows the estimated and observed processes for the macroeconomic variables and bond yields. The correlation between the implied process for $\Delta c_t^* = z_t + \Delta x_t$ and the observed consumption growth is 0.20. The significant difference in the variability of Δc_t^* and consumption growth reflects the inability of consumption growth to capture the variability of yields. The correlation between the observed and estimated inflation is almost 1. The correlation between the observed and estimated short-term rates is 0.94. In particular, the estimation has problems capturing the level of the short-term rate during the period 1993-2000. The estimation does a better job capturing long-term bond yields, with correlations very close to 1 between the observed and estimated processes.

Figure 2 shows the implied values for the latent factor, z_t, and changes in the output gap, Δx_t. The correlation of the short-term rate with the latent factor is 0.85. This correlation increases to 0.95 for the 10-year bond yield. It implies that inflation and the output gap in the estimation have a higher explanatory power for short-term bond maturities. The output gap has an implied first-order autocorrelation coefficient of $\phi_x = 0.89$. The high persistence in the output gap is driven by the high policy credibility δ. Changes in the output gap are large and volatile during the first part of the sample.

Table 3 compares some unconditional properties implied by the model with data statistics. While the average levels of bond spreads in Panel A are captured relatively well, the unconditional volatility of the short-term rate and bond yields is lower than in the data, especially for the short-term rate. The model-implied Campbell-Shiller coefficients are different from one. However, the coefficients are far from those in the data, especially for long maturities. In particular, the model fails to capture that these coefficients become more negative with maturity. Panel B shows that the model captures the negative correlation between inflation and consumption growth. However, the volatility and autocorrelation of consumption growth in the model are, respectively, higher and lower than in the data. Panel C shows the model-implied coefficients of the predictive regressions in equation (2) of four-quarter ahead inflation and consumption growth on bond spreads. The coefficients for the inflation regressions have the right (negative) sign. However, they are significantly more negative than in the data. The regressions of consumption growth show a significant positive reaction of consumption growth to bond spreads. The model-implied R^2s of the regressions, however, are lower than those implied by the data.

4.2 Macroeconomic and bond yield dynamics

The implications of the policy on bond yield dynamics can be understood from the implications of the policy on the volatility of inflation and the output gap. The policy objective function (3) can be decomposed as

$$\begin{aligned}\mathbb{E}\left\{\sum_{t=0}^{\infty}\beta^t\left[\rho(\pi_t-\pi^*)^2+\kappa x_t^2\right]\right\} &= \sum_{t=0}^{\infty}\beta^t\left(\rho\mathbb{E}[\pi_t-\pi^*]^2+\kappa\mathbb{E}[x_t]^2\right) \\ &+ \sum_{t=0}^{\infty}\beta^t\left[\rho\text{var}(\pi_t)+\kappa\text{var}(x_t)\right].\end{aligned}$$

Woodford (2003) refers to the second term as the stabilization component, and proposes to rank policies according to the size of this component. It can be shown that an increase in the relative weight of inflation in the policy objective for a fixed level of credibility involves a reduction in the volatility of inflation and an increase in the volatility of the output gap. On the other hand, an increase in the credibility of the policy for a fixed relative weight of inflation translates into a reduced variability in both the output gap and inflation. The different implications on volatility between increasing ρ and increasing δ are reflected in the properties of the yield curve. Figure 3 presents comparative statics to analyze the effects on bond yield dynamics of changes in the weight of inflation ρ in the policy objective, as well as changes in the credibility of the policy δ. The figure shows that increases in ρ reduce the volatility of inflation at the expense of an increase in the volatility of consumption growth. The increased variability in consumption growth translates into an increased time variation in prices of risk. The levels of the short-rate and bond spreads are not significantly affected. The reduction in the volatility of inflation is reflected in a reduced volatility for the short-term rate and bond yields. However, the volatility of long-term bond yields with respect to short-term rate volatility increases as as result of the increased variability in the prices of risk. An additional effect of this variability is larger deviations from the expectations hypothesis, as captured by the Campbell-Shiller coefficients. The comparative statics for the degree of credibility δ show also a reduction in the variability of inflation as δ increases. In this case, the variability of consumption growth tends to decrease slightly. Bond risk premiums and their variability decline, which is reflected in lower average bond spreads, lower volatility of long-term yields, and reduced deviations from the expectations hypothesis. In summary, policies that reduce the volatility of both inflation and the output gap are associated to lower spreads, lower yield volatility, and reduced deviations from the expectations hypothesis. On the other hand, policies that involve a tradeoff between lower inflation and higher output gap volatility increase the volatility of long-term yields with respect to the short-term rate and imply larger deviations from the expectations hypothesis. These differences will also be reflected in the economic content of the yield curve.

4.3 Expected future short-term rates and forward rates

Changes in forward rates reflect changes in expectations about future interest rates if the expectations hypothesis holds. However, in the presence of bond risk premiums, changes in forward rates can be the result of changes in the compensation for risk in bonds. In this section the difference between forward rates and expected future short-term rates is analyzed, along with how this difference depends on the type of monetary policy that is conducted.

The one-period forward rate at time t between $t+h$ and $t+h+1$ is

$$f_{t,h} = (h+1)i_t^{(h+1)} - hi_t^{(h)},$$

by no-arbitrage. From equation (23), this rate can be expressed as

$$f_{t,h} \quad = \quad \mathbb{E}_t[i_{t+h}] + \mathbb{E}_t\left[xr_{t,t+1}^{(h+1)}\right] + \mathbb{E}_t\left[\sum_{j=1}^{h-1} \Delta xr_{t+j,t+j+1}^{(h+1-j)}\right]$$

where $\Delta xr_{t+j,t+j+1}^{(h+1-j)} \equiv xr_{t+j,t+j+1}^{(h+1-j)} - xr_{t+j-1,t+j}^{(h+1-j)}$ captures changes in bond excess returns. Forward rates then contain expectations on future short-term rates, as well as expectations on bond excess returns. Variations in expected excess returns on bonds generate differences between changes in forward rates and changes in expected future rates. Consider first a positive latent factor shock of one standard deviation. This shock increases the short-term forward rate $f_{t,1}$ and the expected short-term rate $\mathbb{E}_t[i_{t+1}]$ by 35 and 32 bps, respectively, in annualized terms. It implies an increase in the associated bond risk premium of 3 bps. The effect increases on long-term maturities. The latent factor shock increases the forward rate $f_{t,40}$ and the expected rate $\mathbb{E}_t[i_{t+40}]$ by 26 and 18 bps, respectively, in annualized terms. The effect of changes in bond risk premiums is 8 bps. Consider now a positive supply shock of one standard deviation. This shock increases the short-term forward rate $f_{t,1}$ and the expected short-term rate $\mathbb{E}_t[i_{t+1}]$ by 32 and 40 bps, respectively, in annualized terms. That is, there is a reduction in bond risk premiums of 8 bps. The effect reverses for long-term maturities. The shock increases the forward rate $f_{t,40}$ and the expected rate $\mathbb{E}_t[i_{t+40}]$ by 7 and 2 bps, respectively, in annualized terms. The effect of changes in bond risk premiums is 5 bps. Therefore, according to the estimation, latent factor and supply shocks have very different effects on the response of forward rates and expected future rates as a result of time variation in risk premiums. These effects vary significantly across maturities.

Figure 4 presents the initial response of expected short-term rates and forward rates to the two shocks in the model, $\varepsilon_{z,t}$ and $\varepsilon_{u,t}$, for different values of ρ and δ. A positive latent factor shock increases expected future short-term rates and forward rates at all horizons. Forward rates increase by more than expected short-term rates as a result of an increase in bond risk premiums, as an additional compensation for supply shocks. The impulse responses show that increases in the weight of inflation in the policy objective have significant effects on increasing risk premiums in long-term bonds. This is the result of the increased variability in the output gap. On the other hand, an increase in policy credibility reduces the response of bond risk premiums to latent factor shocks given the reduced variability in the output gap. The figure also shows responses to supply shocks. A positive supply shock increases expected future inflation and expected future rates at all horizons. The response of expected rates decreases with the horizon, the weight of inflation in the policy objective, and the policy credibility. Bond risk premiums also react to supply shocks as these shocks produce changes in the compensation for both latent and supply shocks. The effect on bond risk premiums depends on the horizon. Changes in the weight of inflation in the policy objective do not affect significantly the response of bond risk premiums. An increase in policy credibility reduces the variability of risk premiums and the response of bond risk premiums to supply shocks.

4.4 Expected inflation and breakeven inflation

The yield curve contains information about inflation expectations. Under the expectations hypothesis, inflation expectations are obtained as the difference between the level of a nominal bond yield and the level of a real yield with comparable maturity, or breakeven inflation. This result is independent from monetary policy. Deviations from the expectations hypothesis, however, imply that the difference between nominal and real yields contains also an inflation risk premium. This premium may be time varying and depend on the policy. To see this, consider the yield of a real bond with maturity at $t+n$, given by $r_t^{(n)}$. This yield is linked to the real discount factor $M_{t,t+n}^{\text{real}}$ by the no-arbitrage equation

$$e^{-r_t^{(n)}} = \mathbb{E}_t \left[M_{t,t+n}^{\text{real}} \right].$$

From this equation and equation (15) for the nominal yield, the difference between nominal and real yields is

$$i_t^{(n)} - r_t^{(n)} = \mathbb{E}_t \left[\pi_{t,t+n} \right] - \frac{n}{2} \text{var}_t(\pi_{t,t+n}) + \text{cov}_t(m_{t,t+n}^{\text{real}}, \pi_{t,t+n}),$$

where $m_{t,t+n}^{\text{real}} \equiv \log M_{t,t+n}^{\text{real}}$ and

$$\pi_{t,t+n} = \frac{1}{n} \sum_{i=1}^{n} \pi_{t+i},$$

is the average inflation from t to $t+n$. The equation shows that the difference between real and nominal yields contains expectations about future inflation, a Jensen's inequality term, and a covariance term between the real discount factor and inflation. The last component captures an inflation risk premium that is potentially time varying. The inflation risk premium may be affected by monetary policy since the policy affects inflation and the real discount factor through its effects on the output gap. Result 2 describes the real discount factor in terms of economic parameters and the dynamics of the state variables using the affine framework in Section 3.

Result 2. *The process for the real discount factor is represented by equations* (18)*, and* (19)*,* *when the state variables follow the process in Result 1 and*

$$\Gamma_0 = -\log\beta + \gamma(1-\phi_z)\theta_z - \frac{1}{2}\gamma^2\sigma_z^2 - \frac{1}{2}\gamma^2\phi_{x,u}^2\sigma_u^2,$$

$$\Gamma_1 = \begin{pmatrix} \gamma\phi_z - \eta\mu_r \\ -\phi_{x,u}\left[\gamma(1-\phi_u+\phi_x)+\eta\mu_r\right] \\ -\gamma(1-\phi_x)\phi_x + \eta(1-\phi_x)\mu_r \end{pmatrix},$$

$$\lambda_0 = \begin{pmatrix} \gamma \\ \gamma\phi_{x,u} \end{pmatrix}, \quad \lambda_1 = \eta \begin{pmatrix} 1 \\ \phi_{x,u} \end{pmatrix} \begin{pmatrix} 1, & \phi_{x,u}, & -(1-\phi_x) \end{pmatrix}, \quad \mathbb{A}_{3,2} = \begin{bmatrix} \mathbb{I}_{2\times 2} \\ \mathbf{0}_{1\times 2} \end{bmatrix},$$

and

$$\mu_r = \gamma\left(\sigma_z^2 + \phi_{x,u}^2\sigma_u^2\right).$$

Proof. The proof is similar to the one for Result 1 for a real discount factor given by $M_{t,t+1}^{\text{real}} = \beta^n\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\gamma}\left(\frac{Q_{t+1}}{Q_t}\right)$. □

Consider the responses of inflation expectations and the difference in nominal and real rates to latent factor and supply shocks. The difference in responses captures the variation in the inflation risk premiums. By construction, expected inflation is not affected by latent factor shocks. However, nominal and real yields of comparable maturities react to these shocks since the implied inflation risk premiums change. A positive shock of one standard deviation increases the difference $i_t - r_t$ by 8 bps (annualized). For longer maturities, the effect is amplified. For instance, the change in $i_t^{(40)} - r_t^{(40)}$ is 22 bps (annualized). Supply shocks have effects on inflation expectations and inflation risk premiums. A positive supply shock of one standard deviation increases the short-term inflation expectation $\mathbb{E}_t[\pi_{t+1}]$ by 122 bps and the 10-year annualized inflation expectation $\mathbb{E}_t[\pi_{t,t+40}]$ by 16 bps. The difference

$i_t - r_t$ increases by 66 bps, and the difference $i_t^{(40)} - r_t^{(40)}$ increases by 14 bps. This implies that inflation risk premiums decline after a positive supply shock. The effect on inflation risk premiums decreases with the maturity of the bond. The effects of changes in the weight of inflation in the policy objective and policy credibility on the difference between nominal and real yields are also examined. Figure 5 shows comparative statics of the initial responses of inflation expectations and inflation risk premiums for different levels of ρ and δ. The response of inflation risk premiums to latent factor shocks is relatively stable across different weights of inflation in the objective function. On the other hand, this response decreases considerably for long-term maturities as the policy credibility increases. This is the result of the reduced covariance between changes in the output gap and inflation implied by gains in credibility. With respect to supply shocks, inflation expectations react less to supply shocks as the weight of inflation and the policy credibility increases. The effect on the inflation risk premiums increases as ρ increases, and decreases as δ increases. This is a direct effect of the opposite effects on the volatility of the output gap of a higher inflation weight and a higher policy credibility. Higher volatility in the output gap implies larger variation in prices of risk and then larger variation in inflation risk premiums.

4.5 Predictive power of the yield curve

Traditionally, spreads between long-term yields and a short-term rate have been used to forecast macroeconomic variables. If bond risk premiums are constant, the forecast ability of spreads is entirely driven by their information on expected future rates. If bond risk premiums vary over time, the forecast ability of spreads can be determined by risk premiums. In this section, predictive regressions are examined for inflation and consumption growth on spreads and their expectations hypothesis (EH) component. The comparison of these regressions capture the effect of time-varying risk premiums on the predictive power of the yield curve. Regression coefficients for different policy parameter values are compared to analyze the effect of monetary policy on the predictive power of yields.

Let $mv_t = \{\pi_t,\ \Delta c_t\}$ be the set of macroeconomic variables to analyze. We run regressions of the form

$$mv_{t,t+h} = \alpha_{mv,h} + \boldsymbol{\beta}_{mv,h}^{\top}\hat{\mathbf{s}}_t + \varepsilon_{mv,t+h}, \tag{25}$$

where $mv_{t,t+h} = \frac{1}{h}\sum_{i=1}^{h} mv_{t+i}$ is inflation or consumption growth between periods t and $t+h$. The macroeconomic variable can be written in terms of the state variables and observational error as $mv_{t+i} = e_{mv}^{\top}\mathbf{s}_{t+i} + \upsilon_{mv}\epsilon_{mv,t+i}$. The regressors $\hat{\mathbf{s}}_t$ can be expressed as linear combinations of the original state variables. That is, $\hat{\mathbf{s}}_t = \mathcal{C} + \mathcal{D}\mathbf{s}_t$, for appropriate $\mathcal{C}$ and $\mathcal{D}$. We use bond spreads and their EH component as the regressors in univariate regressions. The regression using the spread corresponds to equation (2). Similar to Ang, Piazzesi and Wei (2006), it can be shown that the regression coefficients are given by[6]

$$\boldsymbol{\beta}_{mv,h} = \left(\mathcal{D}\mathrm{var}(\mathbf{s}_t)\mathcal{D}^{\top}\right)^{-1}\mathcal{D}\mathrm{var}(\mathbf{s}_t)\tilde{\Phi}_h^{\top}e_{mv},$$

where $\tilde{\Phi}_h = \frac{1}{h}\Phi(\mathbb{I}-\Phi)^{-1}(\mathbb{I}-\Phi^h)$, and the model-implied R^2 associated to the regression is

$$R^2_{mv,h} = \frac{\boldsymbol{\beta}_{mv,h}^{\top}\mathcal{D}\mathrm{var}(\mathbf{s}_t)\mathcal{D}^{\top}\boldsymbol{\beta}_{mv,h}}{e_{mv}^{\top}\left[\tilde{\Phi}_h\mathrm{var}(\mathbf{s}_t)\tilde{\Phi}_h^{\top} + (1/h^2)\sum_{i=1}^{h}\sum_{j=1}^{i}\Phi^{i-j}\Sigma_{\Psi}(\Phi^{i-j})^{\top}\right]e_{mv} + (1/h)\upsilon_{mv}^2}.$$

[6]This derivation is obtained using the fact that, from equation (17), the process for the state variables at time $t+h$ is

$$\mathbf{s}_{t+h} = (\mathbb{I}-\Phi^h)\theta + \Phi^h\mathbf{s}_t + \sum_{j=1}^{h}\Phi^{h-j}\Psi^{\top}\Sigma^{1/2}\varepsilon_{t+j}.$$

The unconditional variance of the state variables, $\mathrm{var}(\mathbf{s}_t)$, satisfies the Lyapunov equation $\mathrm{var}(\mathbf{s}_t) = \Phi\mathrm{var}(\mathbf{s}_t)\Phi^{\top} + \Sigma_{\Psi}$.

Consider first the predictive regressions for inflation. Figure 6 shows that a positive spread or a positive EH component forecasts a negative inflation. The regression coefficients are less negative as the maturity of the bond spread (or its EH component) used as regressor increases. The comparative statics related to the weight of inflation in the policy objective show that larger values for ρ decrease the R^2s in the regressions. That is, a monetary policy that is more conservative about inflation decreases the predictive power of the yield curve. The R^2 of the regression using the EH component is more sensitive to ρ than the R^2 of the regression using the spread. That is, the role of bond risk premiums explaining the predictability of inflation in the yield curve increases as ρ increases. On the other hand, the comparative statics for δ show that credibility improvements tend to increase the power of spreads to predict future inflation, while the EH component of spreads decreases its predictive ability.

The results of the predictive regressions for consumption growth are presented in Figure 7. Positive spreads predict positive consumption growth. The regression coefficients and R^2s are smaller when longer maturity spreads are used as regressors. On the other hand, positive EH components of spreads predict negative consumption growth. That is, the existence of bond risk premiums that vary over time have a dramatic effect on the predictive power of spreads for consumption growth. Positive changes in bond risk premiums predict growth in consumption. The comparative statics for ρ show an increase in R^2's for regressions using spreads or their EH components as the monetary policy pays more attention to inflation. The opposite is observed as the policy credibility increases. Improvements in policy credibility reduce the ability of the yield curve to predict consumption growth.

5 Discussion

Section 4 shows that the information in the term structure of interest rates can be very sensitive to monetary policy. The weights assigned to output and inflation stabilization in the policy objective and the credibility of the policy affect the joint dynamics of macroeconomic variables and bond yields. The predictive power and the economic content of yields and bond risk premiums is then affected by the policy. This suggests that changes in bond yield dynamics and predictive power can be helpful in identifying changes in monetary policy.

Table 1 in Section 2 shows important differences across periods in macroeconomic and bond yield dynamics, and the predictive power of the yield curve. The 1971-1979 period is characterized by lower spreads, lower yield volatility, larger deviations from the expectations hypothesis, and larger R^2s in predictive regressions for inflation and consumption growth, with respect to the 1987-2005 period. The volatility of macroeconomic variables was also larger for the pre-1979 period. A monetary policy that assigns more weight to inflation in the policy objective can explain some of the changes observed during the Greenspan era. An increased attention to inflation in the policy results in a lower volatility of inflation and a higher volatility of the output gap. A more volatile output translates into larger and more volatile bond risk premiums. The increased level of bond risk premiums is reflected in larger bond spreads. The increased volatility in the premiums is reflected in an increased volatility of long-term bond yields with respect to the short-term rate. Less variability in inflation reduces the ability of bond spreads to predict inflation. This is consistent with the differences between the two periods. The average yield spread between the 10-year bond and the 3-month rate increased from 89 to 191 bps. The ratio between the volatility of the 10-year bond yield and the volatility of the short-term rate increased from 0.47 to 0.73. The R^2 of a predictive regression for inflation using the 10-year bond spread declined from 0.70

to 0.06. This is also consistent with the results in Clarida, Galí and Gertler (2000) who find that post-1979 estimated policy rules are more sensitive to inflation than pre-1979 rules.

However, there are developments in bond yield and macroeconomic dynamics that are not consistent with the story of a monetary authority paying more attention to inflation. For instance, the volatility of consumption growth and bond yields declined during the Greenspan era. Simultaneously, the Campbell-Shiller regression coefficients imply reduced deviations from the expectations hypothesis. Also, the correlation between consumption growth and inflation is less negative, and the predictive ability of bond spreads for consumption growth declined. These developments are consistent with an increased credibility in the policy, or with economic developments that may not be directly related to monetary policy. For instance, the Greenspan era followed the drastic decline in the volatility of output and other macroeconomic variables known as the "Great Moderation." This shift can be related to changes in private sector behavior and not necessarily connected to monetary policy. Further research is required to disentangle the different channels affecting the joint dynamics of macroeconomic variables and bond yields.

6 Conclusion

The forward-looking nature of financial assets makes them ideal for obtaining information about future economic conditions. However, the reliability of this information is limited by our knowledge of the economic drivers of assets' risk premiums. This is particularly evidenced by the yield curve. The sources of changes over time in its predictive ability are not well understood. This paper estimates a semi-structural model to show that monetary policy can significantly affect the information content of bond yields through its effects on the variability of bond risk premiums. Changes in the policy objectives or changes in the policy credibility modify the information in the curve. An increased weight on inflation stabilization or a decreased credibility increases the variability of real variables and bond risk premiums. This is reflected in larger deviations from the expectations hypothesis, greater differences between changes in forward rates and expected short-term rates, greater differences between changes in breakeven inflation and expected inflation, and reduced and increased ability of yield spreads to predict inflation and consumption growth, respectively. The correct interpretation of yield movements requires then the identification of the monetary policy regime.

Further research is needed to understand the fundamental drivers of compensations for risk in the yield curve. This analysis is a first step toward understanding the links between the content of the curve and optimal monetary policy. It can be extended in several dimensions. For instance, the latent factor in the model explains a significant variability of yields, but has limited economic interpretation. It is desirable to specify a completely structural model of the economy capturing all variation in risk premiums from first principles. Also, obtaining information from the curve for policy purposes may have important effects on the yield curve. These effects can be analyzed by allowing the policymaker in the model to react to bond yields to implement the optimal policy.

Appendix

A Monetary Policy Problem

The monetary policy under imperfect credibility in Section 3.1 becomes

$$\min_{\{\pi_t, x_t\}} \rho(\pi_0 - \pi^*)^2 + \kappa x_0^2 + \delta \mathbb{E} \left\{ \sum_{t=1}^{\infty} \beta^t \left[\rho(\pi_t - \pi^*)^2 + \kappa x_t^2 \right] \right\}$$

subject to

$$\pi_t - \pi^* = \kappa x_t + \beta \delta \mathbb{E}_t \left[\pi_{t+1} - \pi^* \right] + u_t,$$

for all $t \geq 0$, where for each $t > 0$, the policymaker is affected by the constraint above with probability δ. Equation (4) does not affect the problem at this stage since the policy objective does not depend on the short-term interest rate i_t. The first-order conditions for the policy problem become

$$\begin{aligned} \frac{\partial}{\partial \pi_t} &: \quad \beta^t \delta \rho(\pi_t - \pi^*) - \delta \psi_t + \beta \delta^2 \psi_{t-1} = 0, \\ \text{and} \quad \frac{\partial}{\partial x_t} &: \quad \beta^t \delta \kappa x_t + \delta \kappa \psi_t = 0, \end{aligned}$$

for $t > 1$, where ψ_t is the Lagrange multiplier associated with each constraint. Replacing the Lagrange multipliers in the equations above, we obtain

$$\beta^t \delta \rho(\pi_t - \pi^*) = -\beta^t \delta x_t + \beta^t \delta^2 x_{t-1}.$$

The optimality condition (7) follows. Notice that the optimality conditions for $t = \{0, 1\}$ are different. We abstract from this time inconsistency problem. See Woodford (2003) for details.

B The Essentially Affine Term Structure Model

The discrete-time version of the Duffie and Kan (1996) model is derived in Backus, Foresi and Telmer (1998). Consider the k-dimensional vector of state variables $\mathbf{s}_t$ following the first-order vector autoregression in equation (17), where $\mathbb{I}$ is the $k \times k$ identity matrix and $\varepsilon_t \sim \text{IID}\mathcal{N}(0, \mathbb{I})$ is an $m \times 1$ vector that contains m sources of uncertainty. The $k \times k$ matrix Φ is the autoregressive matrix for the set of state variables, θ is a $k \times 1$ vector with the unconditional means of the state variables, and the $m \times k$ matrix Ψ and the $m \times m$ matrix Σ determine the sensitivity of the state variables to the uncertainty. The matrix $\Psi^\top \Sigma \Psi$ describes the conditional covariance structure of the state variables.

The one-period stochastic discount factor $M_{t,t+1}$ is described by equation (18), where the $k \times 1$ vector Γ_1 represents the "factor loadings" for the pricing kernel and the $k \times 1$ vector $\lambda(\mathbf{s}_t)$ contains the potentially time-varying prices of risk. The prices of risk are given by equation (19), where λ_0 is an $m \times 1$ vector, λ_1 is an $m \times k$ matrix, and $\mathbb{A}$ is a $k \times m$ matrix that becomes $\mathbb{I}$ when $k = m$. The quadratic term $\frac{1}{2}\lambda(\mathbf{s}_t)^\top \Sigma \lambda(\mathbf{s}_t)$ is a correction that preserves the linearity of bond yields.

Bond yields are given by equation (20) with coefficients $\mathcal{A}_n$ and $k \times 1$ vectors $\mathcal{B}_n$ obtained recursively as presented in equation (21).

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Table 1: Summary of statistics for bond yields, inflation, and consumption growth, and predictive regressions for the 1971-2005 period and different sub-samples. The Campbell-Shiller regressions for bond yields are described by equation (1). The regressions for inflation and consumption growth are described by equation (2). Standard errors are reported in parenthesis.

	1971:3-2005:4	1971:3-1979:3	1979:4-2005:4	1979:4-1987:3	1987:4-2005:4
Panel A: Short-Term Rate and Bond Yields					
Average 3-month rate	6.11	6.56	6.02	9.41	4.49
Average spread 5-year yield	1.20	0.78	1.3	1.25	1.34
Average spread 10-year yield	1.58	0.89	1.76	1.48	1.91
Standard deviation 3-month rate	3.04	2.00	3.34	3.09	2.05
Standard deviation 5-year yield	2.61	1.06	2.95	2.23	1.73
Standard deviation 10-year yield	2.38	0.94	2.68	2.00	1.50
Campbell-Shiller coefficient 5-year yield	-1.72 (1.01)	-2.17 (1.36)	-1.42 (1.26)	-1.97 (2.41)	-0.62 (1.43)
Campbell-Shiller coefficient 10-year yield	-2.92 (1.45)	-3.99 (1.91)	-2.31 (1.82)	-4.02 (4.00)	-0.64 (1.73)
Panel B: Inflation and Consumption Growth					
Average inflation	4.46	7.08	3.66	5.23	2.95
Average consumption growth	1.98	2.26	1.88	1.99	1.83
Standard deviation inflation	2.66	2.56	2.15	2.80	1.26
Standard deviation consumption growth	1.74	2.12	1.59	2.03	1.35
Autocorrelation inflation	0.84	0.75	0.78	0.80	0.54
Autocorrelation consumption growth	0.41	0.47	0.37	0.47	0.27
Correlation inflation and consumption growth	-0.34	-0.80	-0.30	-0.50	-0.19
Panel C: Predictive Regressions					
Regressions of four-quarter ahead inflation					
5-year spread coefficient	-1.08 (0.15)	-1.66 (0.18)	-0.55 (0.12)	-0.82 (0.15)	-0.23 (0.12)
R^2	0.28	0.73	0.18	0.49	0.05
10-year spread coefficient	-0.96 (0.12)	-1.43 (0.17)	-0.48 (0.1)	-0.73 (0.14)	-0.17 (0.09)
R^2	0.33	0.70	0.21	0.48	0.06
Regressions of four-quarter ahead consumption growth					
5-year spread coefficient	0.53 (0.08)	1.25 (0.16)	0.35 (0.08)	0.62 (0.09)	-0.02 (0.12)
R^2	0.27	0.66	0.15	0.64	0.00
10-year spread coefficient	0.38 (0.06)	1.07 (0.14)	0.24 (0.07)	0.53 (0.08)	0.02 (0.09)
R^2	0.21	0.65	0.11	0.59	0.00

Table 2: Parameter values and associated standard errors implied by the estimation. Standard errors for estimated parameters are based on the outer-product estimate of the information matrix. Standard errors for restricted parameters are computed using the delta method.

Parameter	Description	Value	Standard Error
β	Subjective discount factor	1.0087	0.0003
γ	Curvature parameter	2.2433	0.1102
$\eta \times 10^5$	Preference shock parameter	2.9759	0.3769
κ	Inflation - output gap parameter	0.0240	–
$\pi^* \times 10^{-2}$	Inflation target	1.1148	–
ρ	Relative weight of inflation in policy objective	0.2630	0.0070
δ	Degree of policy credibility	0.9461	0.0013
$\theta_z \times 10^{-3}$	Unconditional mean of latent factor	4.9312	–
ϕ_z	Autocorrelation of latent factor	0.9852	0.0006
$\sigma_z \times 10^{-4}$	Conditional volatility of latent factor	3.2500	–
ϕ_u	Autocorrelation of supply shocks	0.9048	0.0011
$\sigma_u \times 10^{-4}$	Conditional volatility of supply shocks	5.3683	0.0103
$\upsilon_c \times 10^{-3}$	Vol. observational error consumption growth	4.5216	0.2530
$\upsilon_\pi \times 10^{-3}$	Vol. observational error inflation	1.0000	–
$\upsilon_i \times 10^{-3}$	Vol. observational error three-month rate	2.5077	0.2007
$\upsilon_y \times 10^{-3}$	Vol. observational error bond yields	0.9509	0.0116

Table 3: Data and model-implied descriptive statistics. Average values and standard deviations are reported in percentage terms.

	Data 1971:3-2005:4	Model
Panel A: Short-Term Rate and Bond Yields		
Average 3-month rate	6.11	6.11
Average spread 5-year yield	1.20	1.40
Average spread 10-year yield	1.58	1.67
Standard deviation 3-month rate	3.04	2.54
Standard deviation 5-year yield	2.61	2.36
Standard deviation 10-year yield	2.38	2.12
Campbell-Shiller coefficient 5-year yield	-1.72	-0.35
Campbell-Shiller coefficient 10-year yield	-2.92	0.40
Panel B: Inflation and Consumption Growth		
Average inflation	4.46	4.46
Average consumption growth	1.98	1.98
Standard deviation inflation	2.66	2.69
Standard deviation consumption growth	1.74	2.06
Autocorrelation inflation	0.84	0.82
Autocorrelation consumption growth	0.41	0.21
Correlation inflation and consumption growth	-0.34	-0.27
Panel C: Predictive Regressions		
Regressions of four-quarter ahead inflation		
5-year spread coefficient	-1.08	-2.58
R^2	0.28	0.55
10-year spread coefficient	-0.96	-2.00
R^2	0.33	0.57
Regressions of four-quarter ahead consumption growth		
5-year spread coefficient	0.53	0.83
R^2	0.27	0.14
10-year spread coefficient	0.38	0.23
R^2	0.21	0.02

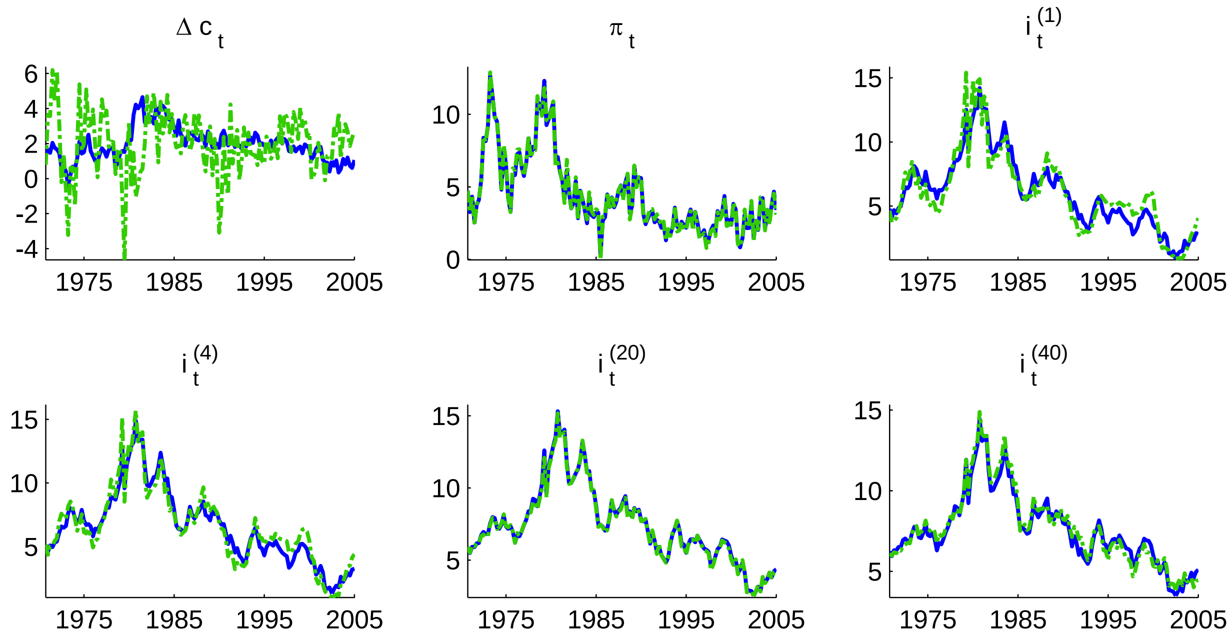

Figure 1: Estimated and data series for consumption growth, inflation, the 3-month interest rate and bond yields for 1-, 5-, and 10- year maturities. The solid (blue) lines are the model-implied series using the parameters in Table 2. The dotted (green) lines are the 1971-2005 data. The series are annualized and presented in percentage terms.

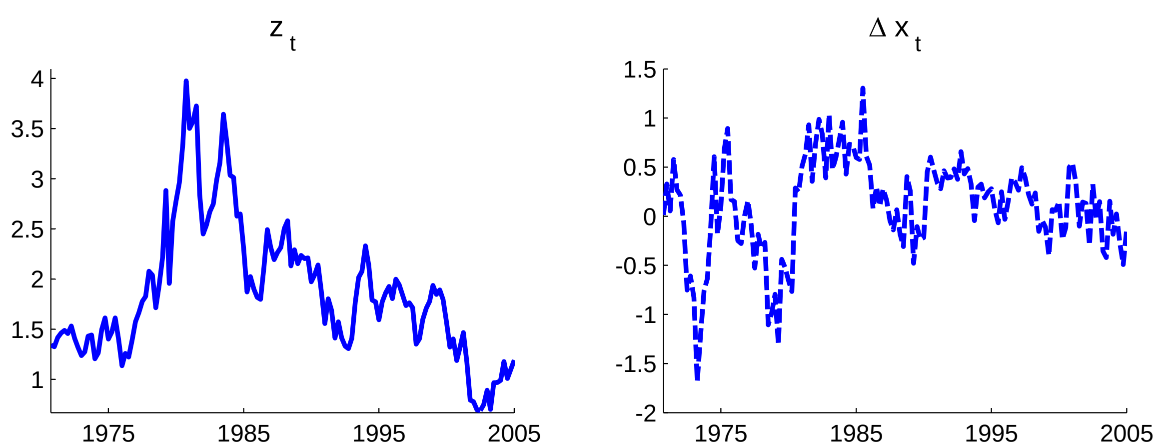

Figure 2: Estimated values for the latent factor z_t and changes in the output gap Δx_t, implied by the parameter values in Table 2. The series are annualized and presented in percentage terms.

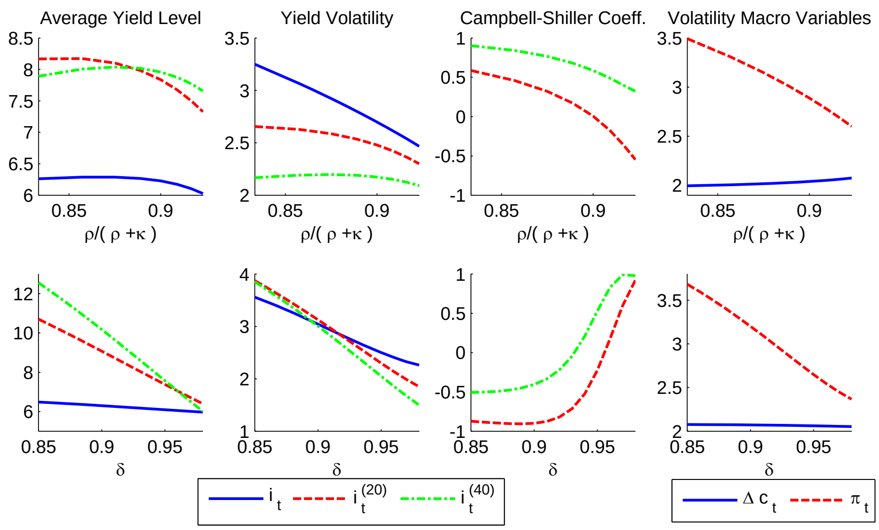

Figure 3: Comparative statics for average level and volatility of yields, Campbell-Shiller coefficients, and volatility of inflation and consumption growth. The first row shows comparative statics with respect to the weight of inflation in the policy objective $\frac{\rho}{\rho+\kappa}$. The second row shows comparative statics with respect to the credibility of the policy δ. The baseline parameter values are presented in Table 2. Average values and volatilities are presented in percentage terms.

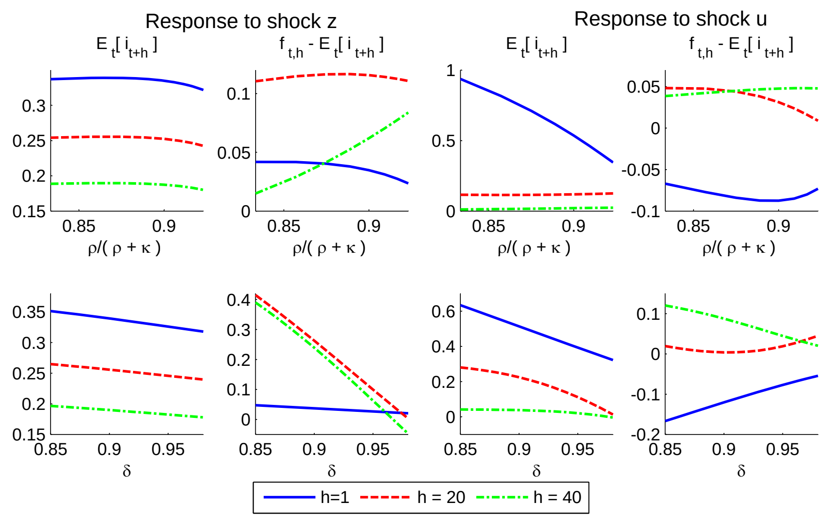

Figure 4: Comparative statics for responses to shocks $\varepsilon_{z,t}$ and $\varepsilon_{u,t}$ of expected future short-term rates, $\mathbb{E}_t[i_{t+h}]$, and forward rates, $f_{t,h}$. The first row shows comparative statics with respect to the weight of inflation in the policy objective $\frac{\rho}{\rho+\kappa}$. The second row shows comparative statics with respect to the credibility of the policy δ. The responses are reported in annualized percentage terms. The baseline parameter values are presented in Table 2.

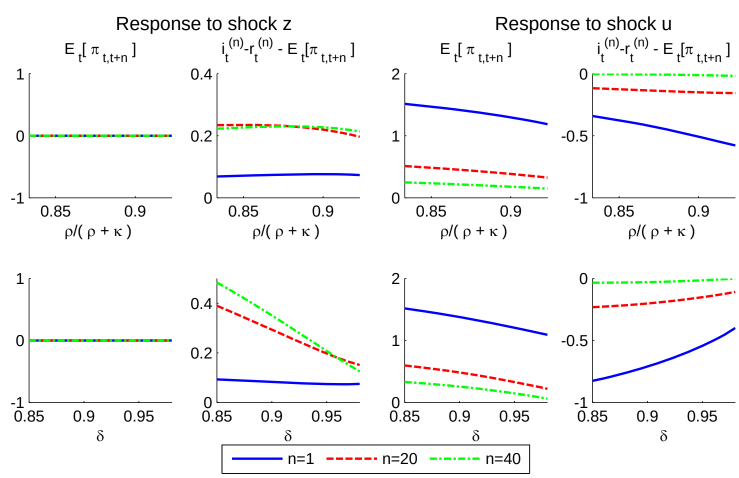

Figure 5: Comparative statics for responses to shocks $\varepsilon_{z,t}$ and $\varepsilon_{u,t}$ of expected future inflation rates, $\mathbb{E}_t[\pi_{t,t+h}]$, and the difference between nominal and real bond yields, $i_t^{(h)} - r_t^{(h)}$. The first row shows comparative statics with respect to the weight of inflation in the policy objective $\frac{\rho}{\rho+\kappa}$. The second row shows comparative statics with respect to the credibility of the policy δ. The responses are reported in annualized percentage terms. The baseline parameter values are presented in Table 2. The responses are presented in percentage terms.

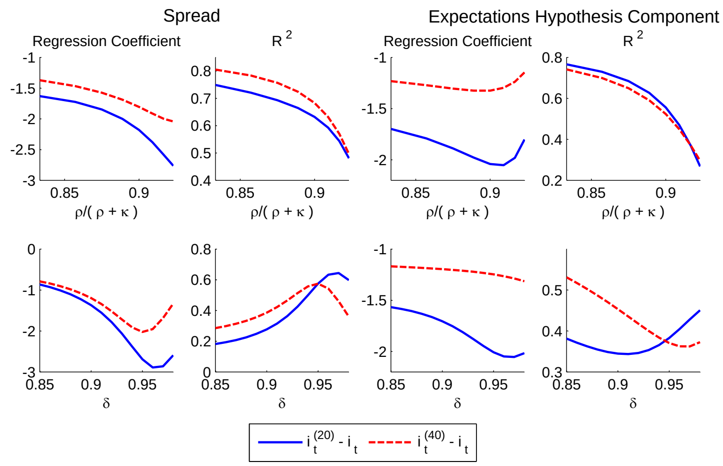

Figure 6: Comparative statics of regression coefficients for predictive regressions for one-year ahead inflation $\pi_{t,t+4}$ in equation (25). The regressor is the spread or its expectations hypothesis component. The first row shows comparative statics with respect to the weight of inflation in the policy objective $\frac{\rho}{\rho+\kappa}$. The second row shows comparative statics with respect to the credibility of the policy δ. The baseline parameter values are presented in Table 2. The responses are presented in percentage terms.

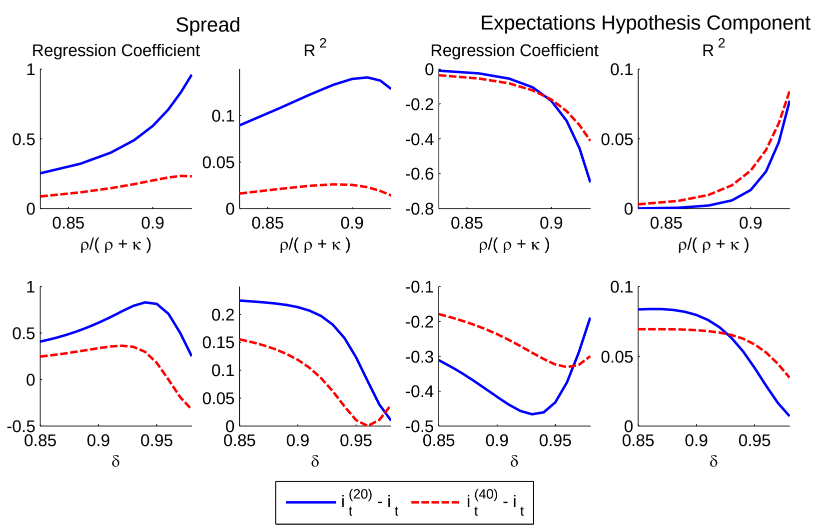

Figure 7: Comparative statics of regression coefficients for predictive regressions for 1-year ahead consumption growth $\Delta c_{t,t+4}$ in equation (25). The regressor is the spread or its expectations hypothesis component. The first row shows comparative statics with respect to the weight of inflation in the policy objective $\frac{\rho}{\rho+\kappa}$. The second row shows comparative statics with respect to the credibility of the policy δ. The baseline parameter values are presented in Table 2.