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Abstract

The term spread may play a major role in a monetary policy rule whenever data revisions of output and inflation are not well behaved. In this paper we use a structural approach based on the indirect inference principle to estimate a standard version of the New Keynesian Monetary (NKM) model augmented with term structure using both revised and real-time data. The estimation results show that the term spread becomes a significant determinant of the U.S. estimated monetary policy rule when revised and real-time data of output and inflation are both considered.

Keywords: NKM model, term structure, monetary policy rule, indirect inference, real-time and revised data.

JEL classification: C32, E30, E52.

1 INTRODUCTION

There is currently a fast growing body of literature (see, for instance, Hördahl, Tristani and Vestin (2006), and references cited therein) that aims to link the New Keynesian Monetary (NKM) model dynamics with the term structure of interest rates.[1] Most papers in this literature assume a sort of dichotomy where the three-equation NKM model is solved first and independently from term structure; that is, they consider no feedback from term structure to the macroeconomy. An exception is Rudebusch and Wu (2008), which builds upon a typical affine no-arbitrage term structure representation with two latent factors (level and slope) by linking these two factors to macroeconomic variables (inflation and output gap) which are determined by an NKM model. In a similar vein and using little macroeconomic structure, Ang, Dong and Piazzesi (2005) consider a single latent factor interpreted as a transformation of Fed policy actions on the short-term rate. In their model, persistent policy shocks are allowed but policy inertia is not.

Another branch of literature (see, for instance, Clarida, Galí and Gertler (2000)) has found empirical evidence that the lagged interest rate is a key component in estimated monetary policy rules. Two alternative interpretations have been proposed in the relevant literature. On the one hand, the significant role of the lagged interest rate may reflect the existence of a traditional concern of central banks for the stability of financial markets (see Goodfriend (1991)). On the other hand, Rudebusch (2002) argues that the significance of the lagged rate in estimated rules is due to the existence of relevant omitted variables. This is because it is hard to reconcile the lack of evidence on the predictive power of the term structure for future values of the short-term interest rate with the existence of policy inertia. Moreover, the existence of omitted variables may result in persistent monetary shocks in estimated rules.[2]

The aim of this paper is to analyze the role of the term spread in the U.S. estimated policy rule by bridging the gap between these two branches of literature. We build upon the first branch by estimating the policy rule of an NKM model augmented with term structure using a classical structural approach based on the indirect inference principle suggested by Smith (1993).

[1] There is also a related body of literature (see, for instance, Ang and Piazzesi (2003), and Diebold, Rudebusch and Aruoba (2003)) linking macro variables to the yield curve using little or no macroeconomic structure.

[2] By using reduced-form estimation approaches, some empirical studies, such as English, Nelson, and Sack (2003) and Gerlach-Kristen (2004), have shown that both policy inertia and persistent shocks enter the estimated monetary policy rule.

Considering term structure in an otherwise standard NKM model introduces two types of feature. On the one hand, it introduces persistent risk premium effects through the IS equation, which are different for instance from those introduced by habit formation à la Furher (2000). As discussed below, the presence of persistent shocks makes it harder to find appropriate instrumental variables when reduced form estimation approaches of monetary policy rules are implemented. On the other hand, it allows us to consider the term spread, in addition to output and inflation, as a potential candidate for explaining the highly persistent dynamics of the short-term policy rate. A pure informational argument to motivate the inclusion of the term spread in the policy rule is the following: a central bank may consider that real-time data on inflation and output available at the time of implementing policy are not a rational forecast of revised data. Thus, a monetary authority may consider that the term spread, which is observed in real-time, may contain relevant information about true, revised data on inflation and output that real-time data on these variables do not provide.[3]

Nowadays, timing and availability of data used in the empirical evaluation of monetary policy rules have become important issues (see, among others, Orphanides (2001), and Ghyssels, Swanson and Callan (2002)).[4] A general conclusion reached from the estimation of monetary policy rules based on real-time data is that it allows for the potential reduction of the effects of parameter uncertainty in actual policy setting, which is relevant when real-time announcements of macroeconomic variables are biased.[5]

The use of real-time data in the estimation of a structural DSGE model may look tricky because it is the decisions of private agents (households and firms) that determine the true (revised) values of macroeconomic variables, such as output and inflation, and they are not observable without error by policymakers in real time. This paper extends the NKM model to include revision processes of output and inflation data, and thus to analyze revised and real-time data together. This extension allows for (i) a joint estimation procedure of both monetary policy rule and revision process parameters, and (ii) an assessment of the interaction between

[3] Empirical evidence found by many researchers (see, for instance, Estrella and Mishkin (1997)) points out that the term spread contains useful information concerning market expectations of both future real economic activity and inflation.

[4] A pioneering study is that of Mankiw, Runkle and Shapiro (1984), who develop a theoretical framework for analyzing preliminary announcements of economic data and apply that framework to the money stock.

[5] Arouba (2008) documents the empirical properties of revisions to major macroeconomic variables in the U.S. and points out that they are not white noise. That is, they do not satisfy simple desirable properties such as zero mean, which indicates that the revisions of initial announcements made by statistical agencies are biased, and that they are predictable using the information set at the time of the initial announcement.

these two sets of parameters.

The empirical results based on revised data for output and inflation show that the monetary policy rule is characterized by both strong policy inertia and persistent policy shocks, whereas the term spread plays a small, but statistically significant role. Policy inertia remains an important determinant when using both revised and real-time data. However, the relative importance of the other two policy rule determinants changes substantially. Thus, the term spread becomes an important determinant whereas the persistence of policy shocks becomes less important, but remains significant. Moreover, the estimates of the revision process parameters show that the initial announcements of output and inflation are not rational forecasts of the true parameters. For instance, a 1% increase in the initial announcement of inflation leads to a downward revision in output of 2.47%.

The rest of the paper is organized as follows. Section 2 introduces the log-linearized approximation of a standard version of the NKM model augmented with term structure. Section 3 describes the structural estimation method used in this paper, motivates its use and discusses how it relates to other estimation methods, such as the Bayesian estimation strategies used in recent literature. Section 4 presents and discusses the estimation results using revised data. Section 5 extends the NKM model to consider revision processes of output and inflation data, and discusses the empirical evidence found when using revised and real-time data together in the estimation process. Section 6 concludes.

2 AN AUGMENTED NEW KEYNESIAN MONETARY MODEL

The model analyzed in this paper is a now-standard version of the NKM model augmented with term structure, which is given by the following set of equations:

$$x_t = E_t x_{t+j} - \tau(i_t^{\{j\}} - \frac{1}{j}\sum_{k=1}^{j} E_t \pi_{t+k}) - \phi(1-\rho_\chi^j)\chi_t + \xi_t^{\{j\}}, \text{ for } j = 1, ..., n \quad (1)$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + z_t, \quad (2)$$

$$i_t = \rho i_{t-1} + (1-\rho)[\psi_1 \pi_t + \psi_2 x_t + \psi_3 (i_t^{\{j\}} - i_t^{\{k\}})] + v_t. \quad (3)$$

where x denotes the output gap (that is, the log-deviation of output with respect to the level of output under flexible prices) and π and $i^{\{j\}}$ denote the deviations from the steady states of inflation and nominal interest rate associated with a j-period maturity bond, respectively. E_t denotes the conditional expectation based on the agents' information set at time t. χ, $\xi^{\{j\}}$, z and v denote aggregate productivity, risk premia, inflation and monetary policy shocks, respectively.[6] Each of these shocks is further assumed to follow a first-order autoregressive process. $\epsilon_{\chi t}$, $\epsilon_{\xi t}^{\{j\}}$, ϵ_{zt} and ϵ_{vt} denote i.i.d. random innovations associated with these shocks, respectively. We introduce two types of shock into the model which affect the IS-equation. On the one hand we have a productivity shock, χ_t, that affects all IS equations, with the impact effect being determined by the persistence of the shock. On the other hand, we introduce a risk premium shock, $\xi_t^{\{j\}}$, into the term structure, which is well justified empirically and has different impacts depending on the horizon considered.

The set of equations (1) comprises the log-linearized first-order conditions obtained from the representative agents' optimization plan (see Appendix 1). Combining two IS equations, say j and l, one gets a highly persistent IS where expected realizations of output gap at different forecast horizons are linked to the ex-ante real interest rate associated with the alternative maturity bonds in the economy:

$$\begin{aligned} E_t x_{t+j} &= E_t x_{t+l} - \tau[(i_t^{\{l\}} - \frac{1}{l}\sum_{k=1}^{l} E_t\pi_{t+k}) - (i_t^{\{j\}} - \frac{1}{j}\sum_{k=1}^{j} E_t\pi_{t+k})] + \\ &\quad \phi(\rho_\chi^l - \rho_\chi^j)\chi_t + \xi_t^{\{l\}} - \xi_t^{\{j\}}, \end{aligned}$$

for $j = 1, ..., n$, and $j \neq l$. With no loss of generality we can assume that $l > j$. This equation can be further manipulated to obtain the following intertemporal IS-equation:

$$i_t^{\{l\}} - i_t^{\{j\}} = \frac{1}{\tau}E_t(x_{t+l} - x_{t+j}) + \frac{1}{l-j}\sum_{k=j+1}^{l} E_t\pi_{t+k} + \frac{\phi}{\tau}\rho_\chi^j(\rho_\chi^{l-j} - 1)\chi_t + \frac{1}{\tau}(\xi_t^{\{l\}} - \xi_t^{\{j\}}). \tag{4}$$

Equation (4) then shows that term spreads are endogenously linked to economic aggregates and that term spreads, expected output gap changes and inflation paths are linked to IS-shocks. Therefore, estimating single-equation policy rules by ordinary least squares is not appropriate because regressors are endogenous. Moreover, when IS-shocks and policy shocks are highly persistent (as widely reported in the relevant literature) it is difficult to find appropriate instrumental variables to control

[6] As discussed by Ireland (2004), there is a long-standing tradition of introducing additional disturbances into dynamic stochastic general equilibrium models until the number of shocks equals the number of data series used in estimation. The reason is that models of this type are quite stylized and introduce fewer shocks than observable variables, which implies that models are stochastically singular. That is, the model implies that certain combinations of endogenous variables are deterministic. If these combinations do not hold in the data, any approach that attempts to estimate the complete model will fail.

for regressors endogeneity. These features further motivate the use of a structural estimation approach.

Equation (2) is the new Phillips curve that is obtained in a sticky price à la Calvo (1983) model where monopolistically competitive firms produce (a continuum of) differentiated goods and each firm faces a downward sloping demand curve for its produced good. The parameter $\beta \in (0,1)$ is the agent discount factor and κ measures the slope of the New Phillips curve, which is related to other structural parameters as follows

$$\kappa = \frac{[(1/\tau) + \eta](1-\omega)(1-\omega\beta)}{\omega}.$$

In particular, κ is a decreasing function of ω. The parameter ω is a measure of the degree of nominal rigidity; a larger ω implies that fewer firms adjust prices in each period and that the expected time between price changes is longer.[7]

Equation (3) is a standard Taylor-type monetary rule where the nominal interest rate exhibits inertial behavior, captured by parameter ρ, for which there are two alternative interpretations proposed in the relevant literature. On the one hand, there are several arguments suggesting that the significant role of the lagged interest rate may reflect the existence of an optimal policy inertia. These arguments range from the traditional concern of central banks for the stability of financial markets (see Goodfriend (1991)) to the more psychological one posed by Lowe and Ellis (1997), who argue that policymakers are likely to be embarrassed by reversals in the direction of interest-rate changes. On the other hand, Rudebusch (2002) argues that the significance of the lagged rate in estimated rules is due to the existence of relevant omitted variables.

The monetary policy rule (3) further assumes that the nominal interest rate responds on the one hand to output gap and inflation, and on the other hand to term spreads, $i_t^{\{j\}} - i_t^{\{k\}}$ for $j > k$. The inclusion of the term spread in the policy rule is well motivated in the relevant literature (as in Laurent (1988) and McCallum (1994)): the term spread is an indicator of monetary policy looseness, so a high value of the term spread calls for corrective actions. Related to this argument for including the term spread in the policy rule is the central bank's aim of monitoring the transmission channel of monetary policy itself by trying to affect the slope of the yield curve. A look at speeches by former Fed Chairman Greenspan reveals that central banks do not seem to be able to affect the slope of the yield curve, and are frustrated by this. The inclusion of the term spread can be further motivated by acknowledging that the term spread, observed in real-time, may contain relevant

[7] See, for instance, Walsh (2003, chapter 5.4) for detailed analytical derivations of the New Phillips curve.

information about revised data on inflation and output that real-time data on these variables do not provide. Moreover, from an econometric perspective, if one accepts Rudebusch's (2002) argument that the significance of the lagged interest rate in estimated policy rules is due to the existence of relevant omitted variables, one may wonder whether the term spread is one of them.

Since the structural econometric approach implemented is computationally quite demanding, we consider an economy with only two bonds: a 4-period bond as the long-term bond and a 1-period bond as the short-term bond. The system of equations (1)-(3) for $j = 1, 4$ (together with eight extra identities involving forecast errors) can be written in matrix form as follows (for the sake of simplicity we further assume that the 1-period bond and the policy interest rate are the same):

$$\Gamma_0 Y_t = \Gamma_1 Y_{t-1} + \Psi \epsilon_t + \Pi \eta_t, \tag{5}$$

where

$$\begin{aligned} Y_t &= (x_t, \pi_t, i_t, i_t^{\{4\}}, E_t x_{t+1}, E_t x_{t+2}, E_t x_{t+3}, E_t x_{t+4}, \\ &\quad E_t \pi_{t+1}, E_t \pi_{t+2}, E_t \pi_{t+3}, E_t \pi_{t+4}, \chi_t, z_t, \xi_t^{\{4\}}, v_t)', \end{aligned}$$

$$\epsilon_t = (\epsilon_{\chi t}, \epsilon_{zt}, \epsilon_{\xi t}^{\{4\}}, \epsilon_{vt})',$$

$$\begin{aligned} \eta_t &= (x_t - E_{t-1}[x_t], E_t[x_{t+1}] - E_{t-1}[x_{t+1}], E_t[x_{t+2}] - E_{t-1}[x_{t+2}], \\ &\quad E_t[x_{t+3}] - E_{t-1}[x_{t+3}], \pi_t - E_{t-1}[\pi_t], E_t[\pi_{t+1}] - E_{t-1}[\pi_{t+1}], \\ &\quad E_t[\pi_{t+2}] - E_{t-1}[\pi_{t+2}], E_t[\pi_{t+3}] - E_{t-1}[\pi_{t+3}])'. \end{aligned}$$

Equation (5) represents a linear rational expectations (LRE) system. It is well known that LRE systems deliver multiple stable equilibrium solutions for certain parameter values. Lubik and Schorfheide (2003) characterize the complete set of LRE models with indeterminacies and provide a numerical method for computing them. In this paper, we impose Taylor's principle (i.e. $\psi_1 > 1$) as a maintained hypothesis in order to deal only with sets of parameter values that imply determinacy (uniqueness) of the rational expectations equilibrium.[8]

The model's solution yields the output gap, x_t. This measure is not observable. In order to estimate the model by simulation, we have to transform the output gap

[8] Appendix 3 shows the estimation results when Taylor's principle is not imposed in the estimation procedure. Two conclusions emerge from this analysis. First, the estimation results are robust to imposing Taylor's principle or not. Second, the estimated set of parameters when Taylor's principle is not imposed still implies determinacy of the rational expectations equilibrium.

into a measure that has an observable counterpart. This is a quite straightforward exercise since the log-deviation of output from its steady state can be defined as the output gap plus the (log of the) flexible-price equilibrium level of output, y_t^f, and the latter can be expressed as a linear function of the productivity shock:

$$y_t^f = \phi \chi_t.$$

The log-deviation of output from its steady state is also unobservable. However, the growth rate of output is observable and its model counterpart is obtained from the first-difference of the log-deviation of output from its steady state.

Similarly, the solution of the model yields the deviations of inflation and the two interest rates from their respective steady states. In order to obtain the levels of inflation and nominal interest rates, we first calibrate the steady-state value of inflation as the sample mean of the inflation rate. Second, using the calibrated value of steady-state inflation and the definitions of the steady-state values of real interest rates associated with bonds at different maturities, we can easily compute the steady-state values of nominal interest rates of bonds at alternative maturities. Third, the level of each nominal rate is obtained by adding the deviation (from its steady-state value) of the nominal rate to its steady-state value computed in the previous step. Finally, since a period is identified with a quarter and the two interest rates are thus measured in quarterlized values, the quarterlized interest rates are transformed into annualized values as in actual data.

3 ESTIMATION PROCEDURE

In order to estimate the structural and policy parameters of the NKM model with term structure, we follow the *indirect inference* principle proposed by Smith (1993), which considers a VAR representation as the auxiliary model. María-Dolores and Vázquez (2006, 2008) are recent applications of this estimation strategy in the context of NKM models. More precisely, we first estimate an unrestricted VAR with four lags in order to summarize the joint dynamics exhibited by U.S. quarterly data on output growth, inflation, the Fed funds rate and the 1-year Treasury rate. The lag length considered is fairly reasonable when using quarterly data. Second, we apply the simulated moments estimator (SME) suggested by Lee and Ingram (1991) and Duffie and Singleton (1993) to estimate the underlying structural and policy parameters of the NKM model. In this vein, Rotemberg and Woodford (1997), Amato and Laubach (2003), Christiano, Eichenbaum and Evans (2005), and Boivin and Giannoni (2006) use a minimum distance estimator based on impulse-response functions instead of VAR coefficients.

This estimation procedure starts by constructing a $p \times 1$ vector with the coefficients of the VAR representation obtained from actual data, denoted by $H_T(\theta_0)$, where p in this application is 78. We have 68 coefficients from a four-lag, four-variable system and 10 extra coefficients from the non-redundant elements of the variance-covariance matrix of the VAR residuals. T denotes the length of the time series data, and θ is a $k \times 1$ vector whose components are the model parameters. The true parameter values are denoted by θ_0. Since our main goal is to estimate policy rule parameters, prior to estimation we split the model parameters into two groups. The first group is formed by the pre-assigned structural parameters β, τ, η, ω. We set $\beta = 0.995$, $\tau = 0.5$, $\gamma = 3.0$ and $\omega = 0.75$, corresponding to standard values assumed in the relevant literature for the discount factor, consumption intertemporal elasticity, the Frisch elasticity and Calvo's probability, respectively. The second group, formed by policy and shock parameters, is the one being estimated. In the NKM model with term structure, the estimated parameters are $\theta = (\rho, \psi_1, \psi_2, \psi_3, \rho_\chi, \rho_\xi^{\{4\}}, \rho_z, \rho_v, \sigma_\chi, \sigma_\xi^{\{4\}}, \sigma_z, \sigma_v)$ and then $k = 12$.[9]

As pointed out by Lee and Ingram (1991), the randomness in the estimator is derived from two sources: the randomness in the actual data and the simulation. The importance of the randomness in the simulation to the covariance matrix of the estimator is decreased by simulating the model a large number of times. For each simulation a $p \times 1$ vector of VAR coefficients, denoted by $H_{N,i}(\theta)$, is obtained from the simulated time series of output growth, inflation and the two interest rates generated from the NKM model, where $N = nT$ is the length of the simulated data. By averaging the m realizations of the simulated coefficients, i.e., $H_N(\theta) = \frac{1}{m}\sum_{i=1}^{m} H_{Ni}(\theta)$, we obtain a measure of the expected value of these coefficients, $E(H_{Ni}(\theta))$. The choice of values for n and m deserves some attention. Gouriéroux, Renault and Touzi (2000) suggest that is important for the sample size of synthetic data to be identical to T (that is, $n = 1$) to get an identical size of finite sample bias in estimators of the auxiliary parameters computed from actual and synthetic data. We make $n = 1$ and $m = 500$ in this application. To generate simulated values of the output growth, inflation and interest rate time series we need the starting values of these variables. For the SME to be consistent, the initial values must have been drawn from a stationary distribution. In practice, to avoid the influence of starting values we generate a realization from the stochastic processes of the four variables of length $200 + T$, discard the first 200 simulated observations, and use only the remaining T observations to carry out the estimation. After two hundred

[9] We consider a six-variable VAR with four lags when estimating the extended NKM model using both revised and real-time data below. In this case, $p = 171$, that is, we have 150 coefficients from a four-lag, six-variable system and 21 extra coefficients from the non-redundant elements of the covariance matrix of the VAR residuals. k is equal to 20 in the extended model (i.e. the twelve parameters of the NKM model plus eight parameters from the revisions processes of output and inflation).

observations have been simulated, the influence of the initial conditions must have disappeared.

The SME of θ_0 is obtained from the minimization of a distance function of VAR coefficients from actual and synthetic data. Formally,

$$\min_{\theta} \; J_T = [H_T(\theta_0) - H_N(\theta)]' W [H_T(\theta_0) - H_N(\theta)],$$

where W^{-1} is the covariance matrix of $H_T(\theta_0)$.

Denoting the solution of the minimization problem by $\hat{\theta}$, Lee and Ingram (1991) and Duffie and Singleton (1993) prove the following results:

$$\sqrt{T}(\hat{\theta} - \theta_0) \rightarrow \mathrm{N}\left[0, \left(1 + \frac{1}{m}\right)(B'WB)^{-1}\right],$$

$$\left(1 + \frac{1}{m}\right) T J_T \rightarrow \chi^2(p - k), \tag{6}$$

where B is a full rank matrix given by $B = E(\frac{\partial H_{Ni}(\theta)}{\partial \theta})$.

The objective function J_T is minimized using the optimization package OPTMUM programmed in GAUSS language. We apply the Broyden-Fletcher-Glodfard-Shanno algorithm. To compute the covariance matrix we need to obtain B. Computation of B requires two steps: first, obtaining the numerical first derivatives of the coefficients of the VAR representation with respect to the estimates of the structural parameters θ for each of the m simulations; second, averaging the m-numerical first derivatives to get B.

At this point, the reader might be wondering: (i) why we do not estimate the NKM model directly by maximum likelihood (ML); and (ii) why we use an unrestricted VAR as the auxiliary model when implementing the indirect inference approach instead of matching structural impulse response functions as in Rotemberg and Woodford (1997). With reference to the first question, it must be stressed that the NKM model is a highly stylized model of a complex world. Therefore, ML estimation of the NKM model will impose strong restrictions which are not satisfied by the data and inferences will be misleading. We believe that one of the main virtues of the indirect inference approach is that in principle econometricians have the possibility of choosing an auxiliary model that imposes looser restrictions than ML. As regards the second question, the NKM model augmented with term structure could be approximated by a VAR. We consider an unrestricted VAR instead of matching the structural impulse responses because a reduced form VAR does not require the arbitrary identification of structural shocks. Moreover, applications of the minimum distance estimator based on the impulse response functions use a diagonal weighting matrix that includes the inverse of each impulse response's variance on the main diagonal. This weighting matrix delivers consistent estimates of the structural parameters, but it is not asymptotically efficient since it does not take into account the whole covariance matrix structure associated with the set of moments. Furthermore, some researchers include additional variables in order to derive 'sensible' impulse responses. For instance, to solve the so called price puzzle a commodity price index is included in the impulse response analysis even though the NKM model says nothing about how the commodity price index is determined.

By following a classical approach, we obviously depart from papers that use a Bayesian approach. The Bayesian estimation approach operates in a different metric and under a different philosophy from frequentist estimators such as indirect inference. Fernández-Villaverde and Rubio-Ramírez (2004) claim that when Bayesian methods are used to estimate DSGE models, parameter estimates and model comparison are consistent even when models are misspecified. An important advantage of the Bayesian approach is the treatment of model uncertainty. Brock, Durlauf and West (2003) attempt to place theoretical and empirical evaluation exercises in a framework that properly accounts for different types of uncertainty and conclude that model uncertainty can be accounted for using standard Bayesian methods, making it useful for policy analysis. There are also papers that rely on the same VAR approximation as we do, but use a flexible Bayesian framework. Del Negro and Schorfheide (2004) and Del Negro, Schorfheide, Smets and Wouters (2007) derive priors from New Keynesian DSGE models for VARs and show that imposing restrictions from the DSGE model non-dogmatically on the VAR produces better results in terms of both forecastability and policymaking. The Bayesian approach suggested by Del Negro and Schorfheide (2004) and the indirect inference approach are two alternative ways (each with its pros and cons) of dealing with potential model misspecification. In this perspective, the indirect inference approach adopted in this paper can be viewed as a way of dealing with model misspecification within a classical rather than a Bayesian framework.

4 EMPIRICAL EVIDENCE

4.1 The data

We consider quarterly U.S. data for the growth rate of output, the inflation rate obtained for the implicit GDP deflator, the Fed funds rate and the 1-year Treasury constant maturity rate during the post-Volcker period (1983:1-2008-1). In addition, we have also considered real-time data on output and inflation as reported by the Federal Reserve Bank of Philadelphia.[10] Figure 1 shows the six time series considered in the paper.

We focus on this sample period for two main reasons. First, the Taylor rule seems to fit better in this period than in the pre-Volcker era. Second, considering the pre-Volcker era opens the door to many more issues studied in the relevant literature, including the presence of macroeconomic switching regimes and the existence of switches in monetary policy (see, for instance, Sims and Zha (2006)). These issues are beyond the scope of this paper.

4.2 Preliminary evidence using revised data

Table 1 shows the estimation results using revised data. The value of the goodness-of-fit statistic, $(1 + 1/m)TJ_T$, which is distributed as a $\chi^2(p-k)$,[11] confirms the hypothesis stated above that the NKM model augmented with term structure is still too stylized to be supported by actual data. The estimation results also show that the policy rule is characterized by (i) a low inflation coefficient ($\psi_1 = 1.0104$) close to the lower bound imposed by Taylor's principle, (ii) high inertia ($\rho = 0.71$) and persistent policy shocks ($\rho_v = 0.80$); and (iii) small coefficients associated with output gap and term spread ($\psi_2 = 0.0$ and $\psi_3 = 0.03$). The estimates of the remaining shock parameters exhibit high persistence and low variance. Based on a structural estimation approach, our empirical results confirm qualitatively the reduced-form estimation results obtained by English et al. (2003) and Gerlach-Kristen (2004) that policy inertia and persistent policy shocks play a role in the U.S. estimated policy rule. The next section considers real-time data on output and inflation in the estimation procedure instead of revised data.

[10] See Croushore and Stark (2001) for the details of the real-time data set.

[11] For the NKM model with term structure the goodness-of-fit statistic is distributed as a $\chi^2(66)$ since the number of VAR coefficients is $p = 78$ and the number of parameters being estimated is $k = 12$.

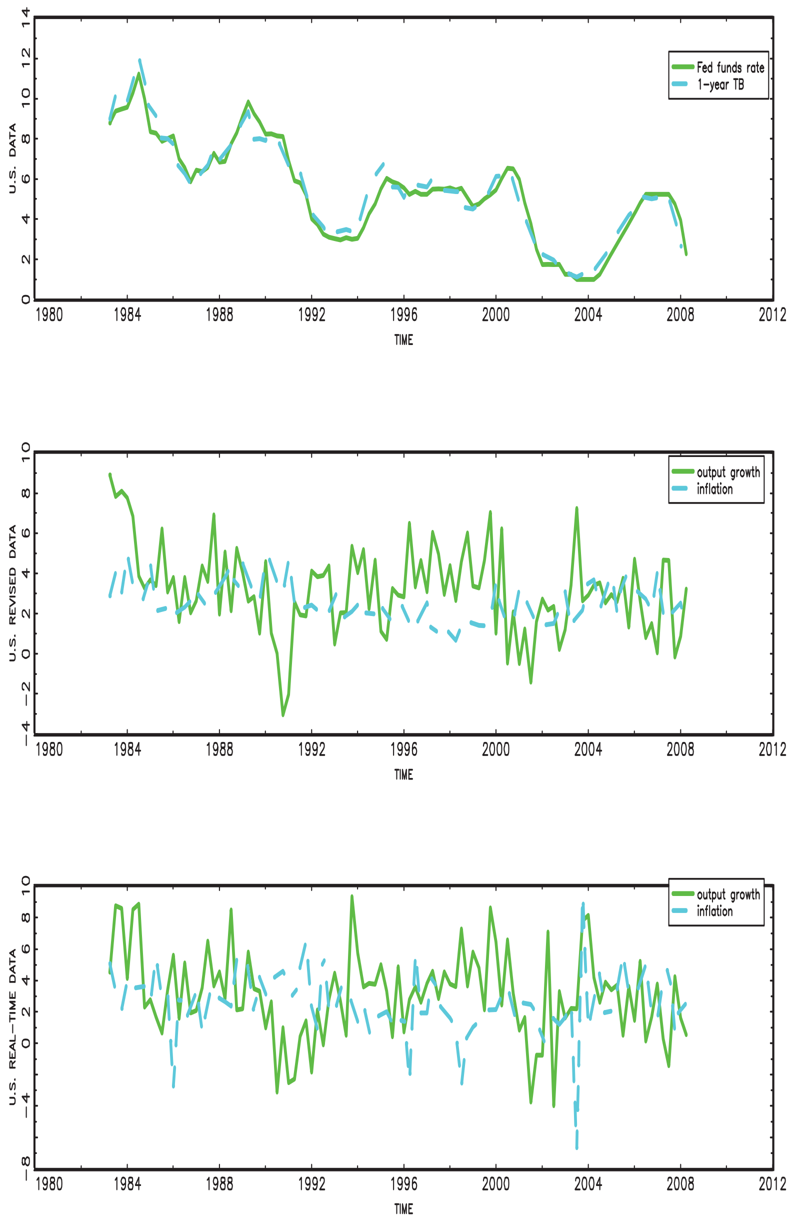

Figure 1: U.S. Time Series

$J_T(\theta)$	6.8230		
Policy parameter	Estimate	Shock parameter	Estimate
ρ	0.7103	ρ_χ	0.8615
	(0.0273)		(0.0136)
ψ_1	1.0104	$\rho_\xi^{\{4\}}$	0.9068
	(0.0344)		(0.0100)
ψ_2	0.0000	ρ_z	0.9950
	(0.0020)		(0.0156)
ψ_3	0.0313	σ_χ	0.0015
	(0.0022)		$(4.1e-04)$
ρ_v	0.7958	$\sigma_\xi^{\{4\}}$	$8.0e-05$
	(0.0241)		$(2.4e-05)$
σ_v	$1.1e-04$	σ_z	$3.8e-05$
	$(1.5e-05)$		$(1.8e-05)$

Table 1: NKM model with term structure using revised data.

Note: Standard errors in parentheses.

5 ESTIMATION USING REAL-TIME DATA

We start this section by estimating the NKM model augmented with term structure using real-time data on output and inflation instead of revised data. If revisions of real-time data were rational forecast errors (i.e. zero mean, serially uncorrelated and uncorrelated with any variable belonging to the information set available at the time of the initial release of data), then the arrival of revised data would not be relevant for policy makers decisions and policy rule estimates would be rather similar using either revised or real-time data. We motivate the inclusion of both term spread and real-time data in the NKM model in two steps. First, we analyze whether real-time data are rational forecasts of revised data. Second, we preliminarily support the argument that if policymakers have evidence that real-time data are not rational forecasts, they may consider that the term spread contains additional relevant information about revised data apart from real-time data for output and inflation.

Following Aruoba (2008), Table 2 shows a set of summary statistics and tests that allows us to analyze whether revision processes for output growth and inflation are “well behaved” (i.e. are white noise processes as stated above). For both revision processes, we cannot reject the null hypothesis that the unconditional mean is null. However, on the one hand, the standard deviations for the two revision processes are quite large, especially when compared to revised data standard deviations (i.e. noise/signal parameter). On the other hand, revision processes are likely to show a first order autocorrelation pattern. The evidence that revisions are not rational forecast errors is further supported by the statistics displayed in panel B. For both output growth and inflation, revision processes are not orthogonal to their respective initial announcements, and the conditional mean is not null. Moreover, the term spread seems to play a role in explaining the revision processes of output growth in addition to real-time output and inflation. This evidence is in line with the empirical evidence provided by Aruoba (2008), who finds that data revisions for these variables (and many others) are not white noise.

Before we discuss the estimation results a word of caution is in order. The estimation of the NKM model with real-time data is likely to be misspecified for two main reasons. First, IS and Phillips curves should be characterized by true (revised) inflation and output data because these two aggregate variables are the result of households and firms choices. Second, since real-time data are observable with a lag, the policy rule must include lagged values of real-time data on output and inflation. We address these two shortcomings by considering an extended version of the NKM model below.

Panel A: Summary statistics

	r_t^y		r_t^π	
Mean	0.074		-0.046	
Median	-0.176		0.033	
Min	-7.053		-7.273	
Max	6.343		8.940	
St. Dev	2.968		2.039	
Noise/signal	1.350		2.076	
corr with initial	0.319		0.238	
AC(1)	-0.229	**	-0.316	***
$E(r_t)$=0. tstat	0.301		-0.302	

Panel B: Conditional Mean

	r_t^y			r_t^π		
	Coef.	t. stat		Coef.	t. stat	
Const	2.702	6.186	***	2.092	11.938	***
$(y_t^r - y_{t-1}^r)$*400	-0.798	-10.500	***	0.040	1.166	
(π_t^r)*400	-0.091	-0.794		-0.879	-19.484	***
Spread	0.937	2.366	**	-0.019	-0.132	
$F_{1\,(4,\,97)}$		38.652	***		131.753	***

Table 2: Revision process analysis. Actual data

Notes: revisions are calculated over annual GDP growth and inflation respectively. Since revisions are likely to have a first order autocorrelation pattern, t-statistics for testing whether unconditional means are null are calculated based on Newey-West corrected standard deviations. Noise/signal is calculated as the standard deviation of the revision over the standard deviation of the revised data. The null hypothesis for the F-test in Panel B or conditional mean hypothesis is that all coefficients for real-time information are null.

$J_T(\theta)$	7.0562		
Policy parameter	Estimate	Shock parameter	Estimate
ρ	0.4023 (0.0846)	ρ_χ	0.9638 (0.0113)
ψ_1	1.9912 (0.6586)	$\rho_\xi^{\{4\}}$	0.9305 (0.0117)
ψ_2	0.0000 (0.1150)	ρ_z	0.9096 (0.0148)
ψ_3	$9.0e-05$ (0.2394)	σ_χ	0.0019 $(5.0e-04)$
ρ_v	0.8353 (0.0267)	$\sigma_\xi^{\{4\}}$	$2.3e-04$ $(9.7e-05)$
σ_v	$7.6e-04$ $(4.0e-04)$	σ_z	$6.0e-04$ $(1.0e-04)$

Table 3: NKM model with term structure using real-time data

Note: Standard errors in parentheses.

In spite of these shortcomings, it is nevertheless useful to estimate the NKM model using only real-time data because it is expected to deliver similar estimation results under the null hypothesis that real-time data are a rational forecast of revised data. Table 3 shows the estimation results using real-time data. Comparing the estimates of the policy rule in Tables 1 and 3, we observe four important differences that can be viewed as support to the evidence displayed in Table 2 that data revisions are not white noise, and that this has an impact on estimated policy rules. First, the policy inertia parameter becomes much smaller when real-time data are used. Second, the estimate of the inflation coefficient is twice as large when real-time data are used, but it is not significantly different from one. Third, the term spread coefficient becomes nonsignificant when real-time data are used. Finally, the size (σ_v) and persistence (ρ_v) of policy shocks are larger when real-time data are used.

The characteristics of the revision processes and the differences in estimated parameters when real-time and revised data are used suggest preliminary evidence that policymakers' decisions could be determined by the availability of data at the time of policy implementation. In order to account for this possibility, we modify the NKM model with term structure in three ways. First, we assume that the IS and Phillips-curve equations are described in terms of revised output and inflation data whereas the policy rule is determined by real-time data on output and inflation. Second, the initial announcement of quarterly (monthly) macroeconomic variables corresponding to a particular quarter (month) appears in the vintage of the next quarter (month), roughly 45 (at least 15) days after the end of the quarter (month). Then, a backward-looking Taylor rule that includes lagged values of real-time data on output and inflation would more accurately approximate the information set available to the Fed at the time of implementing the policy. Third, the model is extended to incorporate two ad-hoc relationships describing the revision processes of output and inflation data, respectively. Formally, the extended NKM model is described by the following set of equations

$$x_t = E_t x_{t+j} - \tau(i_t^{\{j\}} - \frac{1}{j}\sum_{k=1}^{j} E_t \pi_{t+k}) - \phi(1-\rho_\chi^j)\chi_t + \xi_t^{\{j\}}, \text{ for } j = 1 \text{ and } 4 \quad (7)$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + z_t, \quad (8)$$

$$i_t = \rho i_{t-1} + (1-\rho)[\psi_1 \pi_{t-1}^r + \psi_2 x_{t-1}^r + \psi_3(i_t^{\{j\}} - i_t)] + v_t. \quad (9)$$

$$x_t \equiv x_t^r + r_t^x, \quad (10)$$

$$\pi_t \equiv \pi_t^r + r_t^\pi, \quad (11)$$

$$r_t^x = b_{xx} x_t^r + b_{x\pi}\pi_t^r + b_{xsp}(i_t^{\{j\}} - i_t) + \epsilon_{xt}^r, \quad (12)$$

$$r_t^\pi = b_{\pi x} x_t^r + b_{\pi\pi}\pi_t^r + b_{\pi sp}(i_t^{\{j\}} - i_t) + \epsilon_{\pi t}^r. \quad (13)$$

Equations (7)-(8) are just the IS and Phillips curves (they are written out again here for the sake of completeness). Equation (9) describes the policy rule based on real-time data of output and inflation actually available at the time of implementing monetary policy. Equation (10) ((11)) is an identity showing how revised data on output (inflation) is related to real-time output (inflation). Then, r_t^x (r_t^π) denotes the revision of output (inflation).[12] Equations (12) and (13) describe the revision processes associated with output and inflation, respectively. These processes allow for the existence of a contemporaneous correlation between the revision of output and inflation and the initial announcements of these variables.[13] Moreover, we introduce the possibility that revision processes could be determined by the term spread, which is observable with no error and no delay, as preliminarily suggested by the evidence in Table 2. Only under the null hypothesis $H_0 : b_{xx} = b_{x\pi} = b_{\pi x} = b_{\pi\pi} = b_{xsp} = b_{\pi sp} = 0$, can r_t^x and r_t^x be viewed as rational forecast errors. That

[12] By adding the log of potential output on both sides of (10), we have that r_t^x also denotes the revision of the log of output.

[13] The two revision processes assumed do not seek to provide a structural characterization of the revision processes actually followed by statistical agencies, but to provide a simple framework for assessing whether the nature of the revision process might affect the estimated policy rule.

is, the two revision processes are characterized by white noise processes ϵ^r_{xt} and $\epsilon^r_{\pi t}$, with zero mean and variance σ^r_x and σ^r_π, respectively.

For the sake of completeness, we now display the system of equations (7)-(13) together with eight extra identities involving forecast errors in matrix form

$$\Gamma_{R0} Y_{Rt} = \Gamma_{R1} Y_{Rt-1} + \Psi_R \epsilon_{Rt} + \Pi_R \eta_t, \tag{14}$$

where

$$\begin{aligned} Y_{Rt} \;=\; & (x_t, \pi_t, i_t, i_t^{\{4\}}, E_t x_{t+1}, E_t x_{t+2}, E_t x_{t+3}, E_t x_{t+4}, \\ & E_t \pi_{t+1}, E_t \pi_{t+2}, E_t \pi_{t+3}, E_t \pi_{t+4}, \chi_t, z_t, \xi_t^{\{4\}}, v_t, x^r_t, \pi^r_t, r^x_t, r^\pi_t)', \end{aligned}$$

$$\epsilon_{Rt} = (\epsilon_{\chi t}, \epsilon_{zt}, \epsilon^{\{4\}}_{\xi t}, \epsilon_{vt}, \epsilon^r_{xt}, \epsilon^r_{\pi t})'.$$

In order to carry out a joint estimation of the NKM model with term structure and the revision processes using both revised and real-time data, we consider a six-variable VAR with four lags as an auxiliary model to summarize the joint dynamics exhibited by U.S. quarterly data on revised output growth, revised inflation, real-time output growth, real-time inflation, Fed funds rate and 1-year Treasury constant maturity rate.

Table 4 shows the estimation results obtained using both revised and real-time data. The policy inertia parameter is even larger than the estimates obtained above. As in the results obtained using revised data, the inflation parameter is extremely close to one and the output gap coefficient is zero. In contrast with the results based on revised data, the term spread enters the estimated policy rule with a positive, significant coefficient ($\psi_3 = 0.67$) and the shock persistence parameter is much smaller, but still significant ($\rho_v = 0.39$). The large estimated coefficient associated with term spread when both revised and real-time data are considered, compared to the small estimated coefficient found using only revised data, suggests that the informational role of the term spread in the monetary policy rule is quantitatively more important than the other potential roles described above, such as the Fed's attempt to affect the slope of the yield curve.

All the remaining model shocks reported in Table 4 display large persistence. Especially, the risk premium exhibits high persistence ($\rho_\xi^{\{4\}} = 0.99$). The estimation results also show that many revision process parameters are significant, suggesting that real-time data are not rational forecasts in line with the evidence provided in Table 2 for our sample. In particular, the coefficient of inflation in the output

$J_T(\theta)$	13.2124				
Policy parameter	Estimate	Shock parameter	Estimate	Revision parameter	Estimate
ρ	0.9313 (0.0063)	ρ_χ	0.9541 (0.0054)	b_{xx}	0.9487 (0.5565)
ψ_1	1.0000 (0.1333)	$\rho_\xi^{\{4\}}$	0.9900 (0.0068)	$b_{x\pi}$	-2.4722 (0.8005)
ψ_2	0.0000 (0.0044)	ρ_z	0.6286 (0.0323)	b_{xsp}	0.9439 (0.5981)
ψ_3	0.6654 (0.1035)	σ_χ	$4.5e-04$ $(1.2e-04)$	$b_{\pi x}$	-0.0021 (0.0039)
ρ_v	0.3895 (0.0443)	$\sigma_\xi^{\{4\}}$	$1.9e-05$ $(3.2e-06)$	$b_{\pi\pi}$	-0.1979 (0.0907)
σ_v	$4.5e-05$ $(6.0e-06)$	σ_z	$7.2e-04$ $(8.6e-05)$	$b_{\pi sp}$	0.2793 (0.0660)
				σ_x^r	0.0072 (0.0022)
				σ_π^r	$4.0e-04$ $(1.4e-04)$

Table 4: Joint estimation of the NKM model with term structure and the revision processes using both revised and real-time data.
Note: Standard errors in parentheses.

revision equation is large and significant ($b_{x\pi} = -2.47$).[14] Moreover, the term spread and the initial announcements of inflation help to predict inflation revisions, as shown by their respective significant coefficients in the inflation revision process (i.e. $b_{\pi\pi} = -0.20$ and $b_{\pi sp} = 0.28$). Finally, the innovations associated with output revision are much higher than those associated with the inflation revision process.

In order to assess first the nature and then the impact of the term spread information in the monetary policy rule, we perform two additional tests. The first one analyzes a restricted model where revision processes are forced to be well-behaved. Next, we analyze a model where term spread role is forced to be insignificant in the monetary policy rule.

[14] Even when inflation is not significant in the preliminary analysis for the conditional mean of the revision of the output growth process, it becomes significant in the revision process of the output gap (and output level) in the structural estimation approach.

$J_T(\theta')$	15.5893				
Policy parameter	Estimate	Shock parameter	Estimate	Revision parameter	Estimate
ρ	0.9166 (0.0029)	ρ_χ	0.9891 (0.0053)	σ_x^r	0.0045 $(2.6e-04)$
ψ_1	1.0000 (0.0138)	$\rho_\xi^{\{4\}}$	0.9898 (0.0013)	σ_π^r	$2.8e-04$ $(6.0e-05)$
ψ_2	0.0000 $(9.8e-04)$	ρ_z	0.7568 (0.0206)		
ψ_3	0.0455 (0.0030)	σ_χ	$1.4e-04$ $(2.4e-05)$		
ρ_v	0.5359 (0.0247)	$\sigma_\xi^{\{4\}}$	$2.0e-05$ $(4.0e-06)$		
σ_v	$3.8e-05$ $(6.2e-06)$	σ_z	$1.4e-04$ $(2.7e-05)$		

Table 5: Joint estimation of the NKM model with term structure under H_0.
Note: Standard errors in parentheses.

To see if the characteristics of revision processes for both actual and simulated data have an effect on estimated policy rule results, we estimate the system (14) under the null hypothesis that r_t^x and r_t^x are rational forecast errors, $H_0 : b_{xx} = b_{x\pi} = b_{\pi x} = b_{\pi\pi} = b_{xsp} = b_{\pi sp} = 0$. Table 5 shows the estimation results imposing H_0. By using the asymptotic result (6), we know that the null hypothesis H_0 can be tested using the following Wald statistic

$$F_1 = \left(1 + \frac{1}{m}\right) T \left[J_T(\theta') - J_T(\theta)\right] \to \chi^2(6).$$

The F_1-statistic takes the value 231.02. Therefore, we can reject the hypothesis that the revision processes of output and inflation are white noise at any standard significance level. Moreover, comparing the estimation results of Tables 4 and 5 it is interesting to observe that the term spread coefficient becomes very small, but remains significant when the restriction that the two revision processes must be white noise is imposed. This estimation result is in line with the result obtained using only revised data (see Table 1).

Next we estimate the extended NKM model by removing the term spread from the policy rule. A comparison of the impulse response functions obtained from the model with and without the term spread in the policy rule will allow us to assess to what extent considering the term spread in the policy rule affects the transmission mechanism of shocks. But before we do that, it is useful to compare Tables 4 and 6. We observe that by considering term spread in the policy rule (i) the persistence of policy shocks is significantly reduced and (ii) the estimates of many revision process parameters change. In particular, the relative size of the innovations associated with the output and inflation revision processes changes depending on whether or not the term spread is considered in the policy rule. Moreover, by using once again the asymptotic result (6), we know that the significance of the term spread coefficient in the policy rule can be tested using the following Wald statistic

$$F_2 = \left(1 + \frac{1}{m}\right) T \left[J_T(\theta'') - J_T(\theta)\right] \rightarrow \chi^2(1).$$

The F_2-statistic takes the value 26.26. Therefore, we can reject the hypothesis that the term spread does not enter in the policy rule.

Figures 2-5 show the impulse-responses (annualized and in percentage terms) of the endogenous variables of the extended NKM model (14) with (solid line) and without (dotted with diamonds line) considering the term spread in the policy rule to a productivity shock, an inflation shock, a monetary policy shock, and a risk premium shock using the estimates displayed in Tables 4 and 6, respectively. In these figures the dashed lines are 5%-95% confidence bands. The size of the shock is determined by its estimated standard deviation. We can observe that the inclusion of the term spread enhances the short-run effects of the alternative shocks.

Focusing on the impulse-response functions associated with the non-restricted model (solid line), Figure 2 shows that a positive productivity shock reduces the output gap (i.e. the flexible-price equilibrium level of output increases more than the actual one) in the short-run, but the output gap rapidly recovers. This expansive shock also has a negative effect on inflation and interest rates. Figure 3 shows that a positive inflation shock increases inflation and interest rates whereas the output gap decreases. Figure 4 shows the responses to a positive monetary policy shock. The policy shock increases short- and long-term interest rates whereas output gap and inflation decrease. After these initial effects, all variables quickly reach the steady state. Finally, Figure 5 shows that a positive risk premium shock increases the long-term interest rate while slightly reducing the output gap, inflation and the short-term interest rate. These effects are indeed long lasting due to the large persistence of risk premium shocks.

$J_T(\theta'')$	13.4826				
Policy parameter	Estimate	Shock parameter	Estimate	Revision parameter	Estimate
ρ	0.9662	ρ_χ	0.8989	b_{xx}	0.3147
	(0.0068)		(0.0084)		(0.1973)
ψ_1	1.0215	$\rho_\xi^{\{4\}}$	0.9900	$b_{x\pi}$	-2.2454
	(0.1831)		(0.0063)		(0.4321)
ψ_2	0.0000	ρ_z	0.7912	b_{xsp}	0.9848
	(0.0073)		(0.1613)		(0.2866)
ψ_3	0.0	σ_χ	$2.9e-04$	$b_{\pi x}$	0.9942
	–		$(3.8e-05)$		(0.3018)
ρ_v	0.5376	$\sigma_\xi^{\{4\}}$	$4.1e-04$	$b_{\pi\pi}$	-1.2873
	(0.0371)		$(2.9e-05)$		(0.5170)
σ_v	$1.2e-04$	σ_z	$7.3e-06$	$b_{\pi sp}$	0.9850
	$(1.6e-05)$		$(1.4e-06)$		(0.3354)
				σ_x^r	0.0015
					$(3.9e-04)$
				σ_π^r	0.0028
					$(3.9e-04)$

Table 6: Joint estimation of the NKM model without including term spread in the policy rule
Note: Standard errors in parentheses.

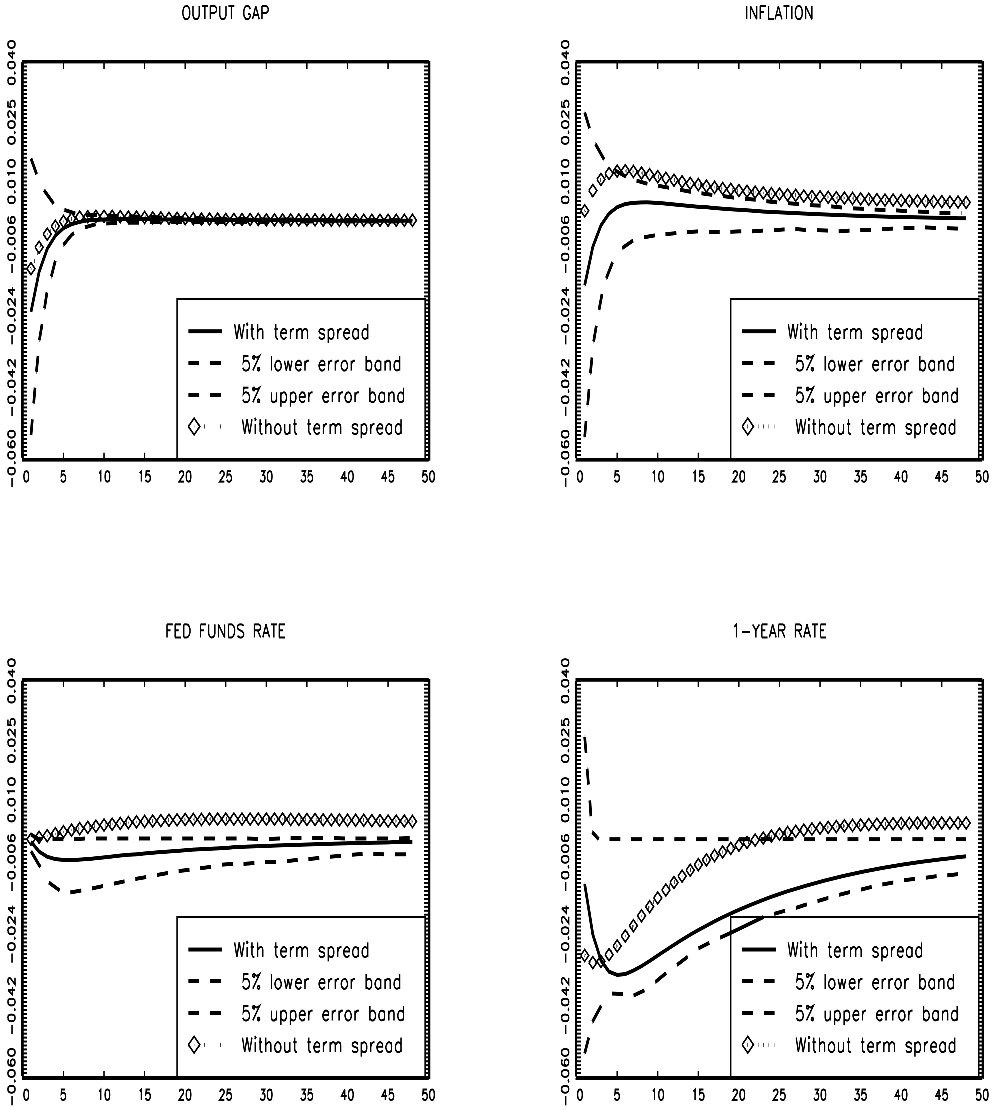

Figure 2: Impulse-responses to a productivity shock

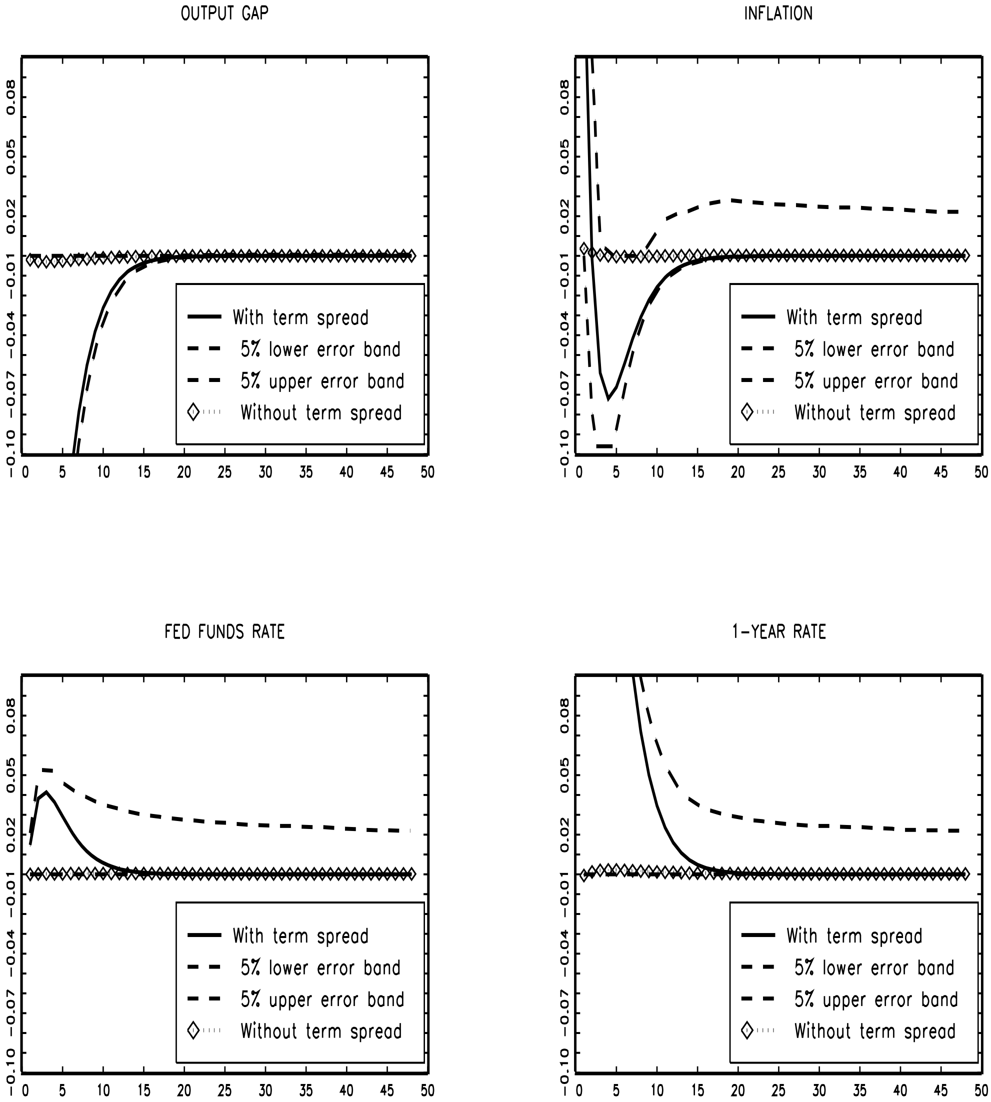

Figure 3: Impulse-responses to an inflation shock.

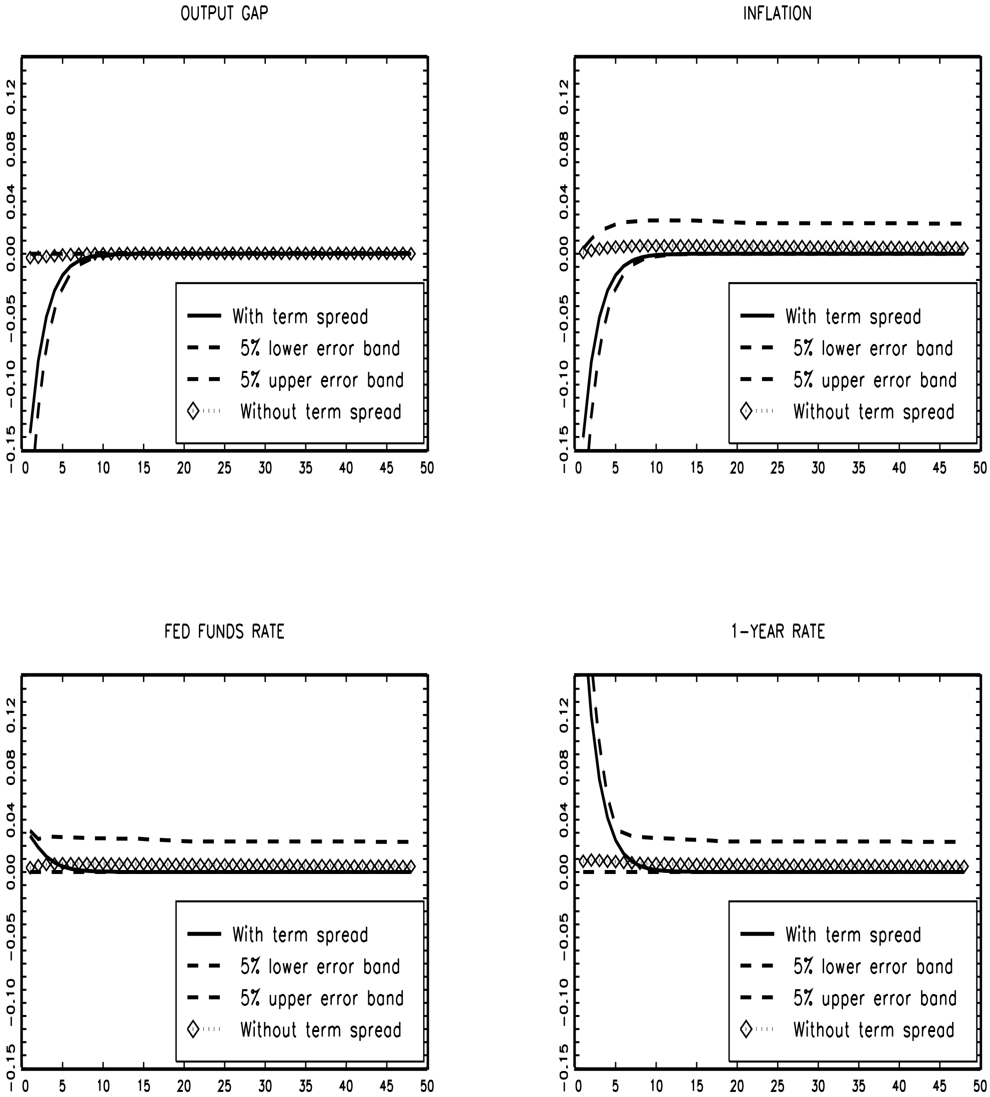

Figure 4: Impulse-responses to a monetary policy shock.

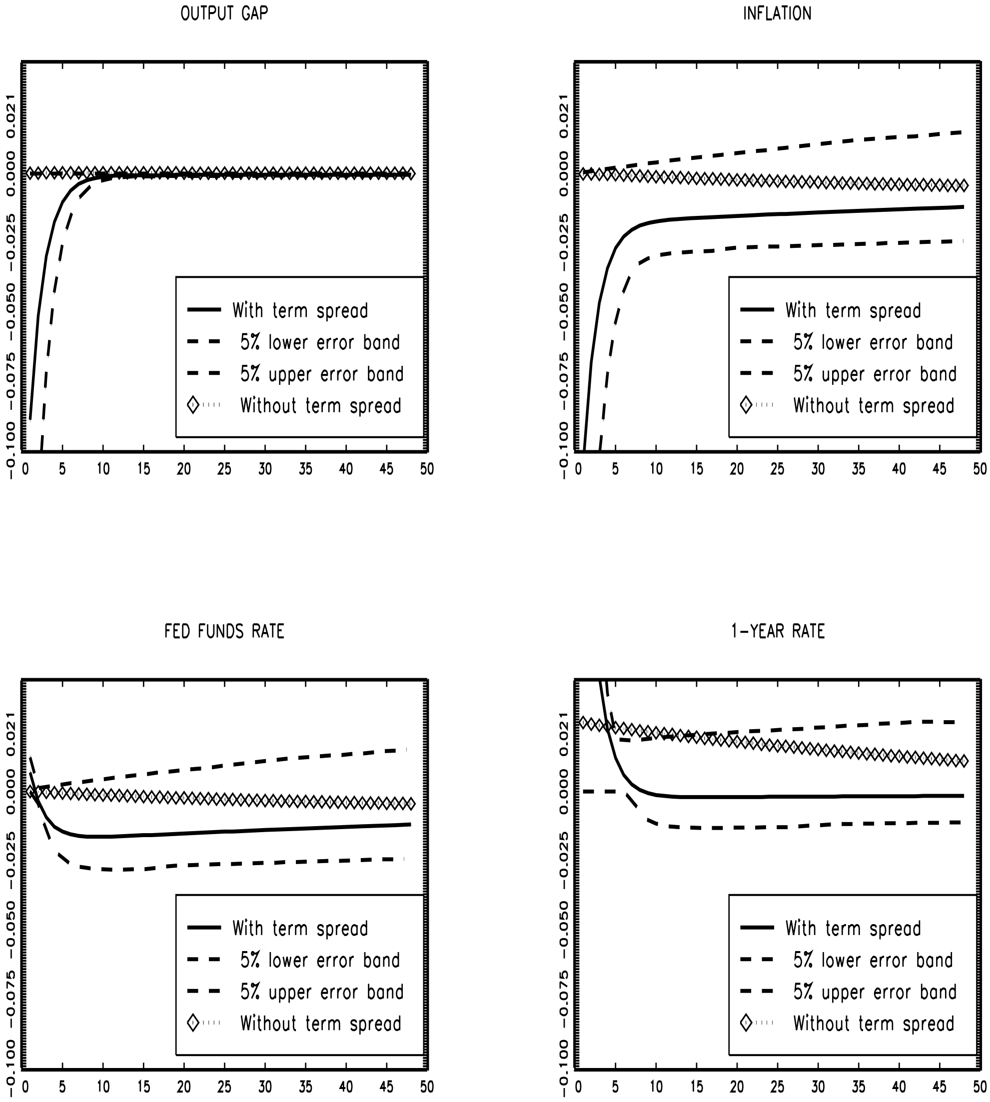

Figure 5: Impulse-responses to a risk premium shock.

Tables 7-8 show a set of summary statistics for the simulated revision processes of output and inflation respectively. The simulated series are computed using the estimates shown in Table 4. By comparing the properties of estimated revision processes obtained from simulated data with those obtained from actual revisions data shown in Table 2, we can assess the ability of the extended NKM model to capture the main regularities observed in actual revision processes of output growth and inflation. For output growth, the model basically replicates the main features of the actual revision process. That is, output growth revision is not well behaved. Standard deviations are quite large both for actual and simulated data. We also find evidence of an autocorrelation pattern, and the conditional mean is clearly different from zero. Using simulated data, all real-time variables seem to play a role in explaining the revision process, which confirms the hypothesis that the revision process is not a rational forecast error. For inflation however, we systematically underestimate the standard deviation of the revision process. This result is driven by the low estimate for the standard deviation of the innovation associated with the inflation revision process. With such a low standard deviation, only for 40% of the simulated series, we could not reject the hypothesis that the unconditional mean is null. Consistent with actual data, the conditional mean is also different from zero using simulated data. Moreover, the term spread adds additional relevant information for explaining the revision process of inflation and output growth both for actual and simulated time series.

6 CONCLUSIONS

This paper follows a structural econometric approach based on the *indirect inference* principle to analyze the relative importance of policy inertia, term spread and persistent monetary policy shocks in the characterization of the estimated monetary policy rule for the U.S. using both revised and real-time data. The framework considered is an NKM model augmented with term structure where the monetary policy rule is one of the building blocks.

The empirical results based on revised data of output and inflation show that the monetary policy rule is characterized by both strong policy inertia and persistent policy shocks, whereas the term spread plays no major role. Policy inertia remains an important determinant when both revised and real-time data are used in the estimation procedure. However, the relative importance of the other two policy rule determinants changes substantially when the revision processes of output and inflation are allowed to be non-rational forecast errors. Thus, the term spread

Panel A: Summary statistics

	Aver. Coef	pctile 1	5	10	50	90	95	99	
Mean	**-0.001**	-0.053	-0.041	-0.032	-0.002	0.029	0.037	0.055	
Median	**0.000**	-0.417	-0.288	-0.225	-0.007	0.215	0.298	0.380	
Min	**-5.501**	-7.992	-7.152	-6.688	-5.431	-4.400	-4.140	-3.805	
Max	**5.477**	3.862	4.147	4.370	5.364	6.753	7.347	8.259	
St. Dev	**2.180**	1.814	1.899	1.949	2.172	2.422	2.466	2.662	
Noise/signal	**5.680**	4.411	4.703	4.903	5.635	6.592	6.838	7.284	
corr with initial	**0.205**	0.009	0.051	0.093	0.199	0.321	0.347	0.404	
AC(1)	**-0.462**	2.510	3.047	3.282	3.900	4.364	4.519	4.711	***
$E(r_t)$=0. tstat		0.005	0.017	0.031	0.143	0.372	0.431	0.552	

Panel B: Conditional Mean

	Aver. Coef	pctile. T-stats 1	5	10	50	90	95	99	
Const	**2.083**	4.451	5.3929	5.832	7.9272	10.205	11.0514	12.4364	***
$(y_t^r - y_{t-1}^r)$*400	**-0.969**	47.645	55.653	59.982	73.629	95.074	103.246	115.056	***
(π_t^r)*400	**-0.535**	3.823	4.830	5.406	7.301	9.629	10.410	11.894	***
Spread	**-0.467**	4.550	5.212	5.670	7.223	9.389	10.000	11.548	***
F (3, 98)		1060.4	1182.4	1273.3	1680.8	2291.4	2523.7	2914.2	***

Table 7: Output growth revision process analysis. Simulated series.

Panel A: Summary statistics

	Aver. Coef	pctile 1	5	10	50	90	95	99	
Mean	**-0.057**	-0.255	-0.193	-0.174	-0.057	0.064	0.091	0.145	
Median	**-0.058**	-0.261	-0.198	-0.173	-0.060	0.068	0.098	0.146	
Min	**-0.758**	-1.130	-1.039	-0.946	-0.742	-0.578	-0.524	-0.443	
Max	**0.652**	0.333	0.418	0.461	0.651	0.841	0.895	1.035	
St. Dev	**0.287**	0.218	0.238	0.251	0.286	0.328	0.340	0.371	
Noise/signal	**0.874**	0.673	0.726	0.756	0.867	1.007	1.051	1.12655	
corr with initial	**0.862**	0.781	0.810	0.825	0.864	0.897	0.905	0.91961	
AC(1)	**0.506**	2.224	2.972	3.2397	4.159	4.729	4.877	5.111	***
E(r_t)=0. tstat		0.041	0.153	0.342	1.692	3.957	4.6894	6.69565	

Panel B: Conditional Mean

	Aver. Coef	pctile. T-stats 1	5	10	50	90	95	99	
Const	**0.557**	1.400	2.115	2.557	4.0951	5.886	6.389	7.67373	**
(y_t^r-y_{t-1}^r)*400	**-0.002**	0.018	0.078	0.1621	0.771	1.835	2.219	2.764	
(π_t^r)*400	**-0.329**	5.105	5.913	6.516	8.894	11.482	12.699	14.192	***
Spread	**0.162**	1.900	2.657	3.139	4.809	7.109	7.908	10.418	**
F (3, 98)		39.1	51.8	59.6	90.5	135.5	157.8	191.1	***

Table 8: Inflation revision process analysis. Simulated series.

becomes a significant determinant of the monetary policy rule whereas policy shock persistence becomes less important, but remains significant.

We can then conclude that the term spread contains useful information for the Fed about revised data on output and inflation, which is not included in their respective initial announcements available at the time of implementing monetary policy.

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APPENDIX 1

This appendix derives the set of IS equations (1). Consider that the representative consumer solves the problem of maximizing

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t),$$

subject to the condition that

$$C_t + \sum_{j=1}^{n} B_t^{\{j\}} \leq Y_t + \sum_{j=1}^{n} B_{t-j}^{\{j\}} R_{t-j}^{\{j\}},$$

where C, N, Y, $B^{\{j\}}$, $R^{\{j\}}$ denote consumption, labor, income, stock of j-period bonds and gross real return of j-period bonds, respectively. Under fairly general conditions this problem has a solution with a finite value of the objective function. The first-order necessary conditions are given by

$$U_C = \lambda_t,$$

$$\beta^j E_t(\lambda_{t+j} R_t^{\{j\}}) = \lambda_t, \text{ for } j = 1, ..., n,$$

where $\{\lambda_t\}$ is a sequence of Lagrange multipliers. Substituting the first equation into each of the j-conditions gives the familiar consumption-based asset pricing equations

$$E_t \left[\beta^j \frac{U_C(C_{t+j}, N_{t+j})}{U_C(C_t, N_t)} R_t^{\{j\}} \right] = 1, \text{ for } j = 1, ..., n.$$

Following Walsh (2003 chapter 5.4), by (i) assuming that the utility function is of the form

$$U(C_t, N_t) = \frac{C_t^{1-1/\tau}}{1 - 1/\tau} - \Psi \frac{N_t^{1+\eta}}{1+\eta};$$

(ii) taking a log-linear approximation for $j = 1$ and $j = 4$; (iii) assuming that output is a linear function solely of labor input and an aggregate productivity shock, e^{χ_t}; (iv) substituting for the market clearing condition $Y_t = C_t$ for all t; and (v) using the definition of output gap (i.e. the gap between actual output and flexible-price equilibrium level of output); we then obtain

$$x_t = E_t x_{t+4} - \tau(i_t^{\{4\}} - \frac{1}{4} \sum_{k=1}^{4} E_t \pi_{t+k}) - \left[\frac{1+\eta}{(1/\tau) + \eta} \right] (1 - \rho_\chi^4) \chi_t,$$

$$x_t = E_t x_{t+1} - \tau(i_t - E_t \pi_{t+1}) - \left[\frac{1+\eta}{(1/\tau) + \eta} \right] (1 - \rho_\chi) \chi_t,$$

where ρ_χ is the autoregressive coefficient of the productivity shock. Finally, we introduce a risk premium shock into the term structure, $\xi_t^{\{4\}}$, where the notation clearly establishes that impact of this shock differs depending on bond maturity

$$x_t = E_t x_{t+4} - \tau(i_t^{\{4\}} - \frac{1}{4}\sum_{k=1}^{4} E_t \pi_{t+k}) - \phi(1-\rho_\chi^4)\chi_t + \xi_t^{\{4\}},$$

where $\phi = \left[\frac{1+\eta}{(1/\tau)+\eta}\right]$.

APPENDIX 2

This appendix shows the matrices involved in Equation (5) and (14). First, we show the matrices in Equation (5).

$$\Gamma_0 = \begin{pmatrix}
1 & 0 & \tau & 0 & -1 & 0 & 0 & 0 & -\tau & 0 & 0 & 0 & \phi(1-\rho_\chi) & 0 & 0 & 0 \\
1 & 0 & 0 & \tau & 0 & 0 & 0 & -1 & \Gamma_0^2 & \Gamma_0^2 & \Gamma_0^2 & \Gamma_0^2 & \phi(1-\rho_\chi^4) & 0 & -1 & 0 \\
-\kappa & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
\Gamma_0^{4,1} & \Gamma_0^{4,2} & \Gamma_0^{4,3} & \Gamma_0^{4,4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{pmatrix},$$

$$
\Gamma_1 = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \rho & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\chi & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_z & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\xi^{\{4\}} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_v \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{pmatrix},
$$

$$
\Pi = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{pmatrix},
$$

$$\Psi = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix},$$

$$\begin{aligned} \Gamma_0^2 &= -\frac{\tau}{4}, \\ \Gamma_0^{4,1} &= -(1-\rho)\psi_2, \\ \Gamma_0^{4,2} &= -(1-\rho)\psi_1, \\ \Gamma_0^{4,3} &= 1 + (1-\rho)\psi_3, \\ \Gamma_0^{4,4} &= -(1-\rho)\psi_3. \end{aligned}$$

Next, we show the matrices involved in Equation (14).

$$
\Gamma_{R0} = \begin{pmatrix}
1 & 0 & \tau & 0 & -1 & 0 & 0 & 0 & -\tau & 0 & 0 & 0 & \phi(1-\rho_\chi) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & \tau & 0 & 0 & 0 & -1 & \Gamma_0^2 & \Gamma_0^2 & \Gamma_0^2 & \Gamma_0^2 & \phi(1-\rho_\chi^4) & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
-\kappa & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \Gamma_0^{4,3} & \Gamma_0^{4,4} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & \Gamma_0^{4,1} & \Gamma_0^{4,2} & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & -1 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -b_{xx} & -b_{x\pi} & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -b_{\pi x} & -b_{\pi\pi} & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix},
$$

$$
\Gamma_{R1} = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \rho & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\chi & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_z & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_\xi^{\{4\}} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_v & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{pmatrix},
$$

$$
\Pi_R = \begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{pmatrix},
$$

$$\Psi_R = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix},$$

$J_T(\theta)$	13.1964				
Policy parameter	Estimate	Shock parameter	Estimate	Revision parameter	Estimate
ρ	0.9316	ρ_χ	0.9542	b_{xx}	0.9490
	(0.0060)		(0.0052)		(0.4793)
ψ_1	0.8925	$\rho_\xi^{\{4\}}$	0.9900	$b_{x\pi}$	-2.4614
	(0.1258)		(0.0065)		(0.6583)
ψ_2	0.0000	ρ_z	0.6216	b_{xsp}	0.9454
	(0.0046)		(0.0303)		(0.6764)
ψ_3	0.6277	σ_χ	$4.1e-04$	$b_{\pi x}$	-0.0016
	(0.1009)		$(1.2e-04)$		(0.0039)
ρ_v	0.3742	$\sigma_\xi^{\{4\}}$	$1.7e-05$	$b_{\pi\pi}$	-0.2799
	(0.0424)		$(3.2e-06)$		(0.0865)
σ_v	$4.6e-05$	σ_z	$7.1e-04$	$b_{\pi sp}$	0.2462
	$(5.9e-06)$		$(8.2e-05)$		(0.0727)
				σ_x^r	0.0072
					(0.0019)
				σ_π^r	$3.8e-04$
					$(1.4e-04)$

Table 9: Joint estimation of the NKM model with term structure and the revision processes without imposing Taylor's principle.
Note: Standard errors in parentheses.

APPENDIX 3

Table 9 shows the estimation results when Taylor principle restriction is not imposed in the estimation procedure. Comparing the estimation results in Tables 4 and 9 we clearly observe that the estimation results are not sensitive to the inclusion of Taylor's principle.

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