Monetary policy regimes and the term structure of interest rates

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ABSTRACT

US monetary policy is investigated using a regime-switching no-arbitrage term structure model that relies on inflation, output, and the short interest rate as factors. The model is complemented with a set of assumptions that allow the dynamics of the private sector to be separated from monetary policy. The monetary policy regimes cannot be estimated if the yield curve is ignored during estimation. Counterfactual analysis evaluates importance of regimes in policy and shocks for the great moderation. The low-volatility regime of exogenous shocks plays an important role. Monetary policy contributes by trading off asymmetric responses of output and inflation under different regimes.

1. Introduction

That monetary policy matters for the real economy is widely accepted in modern macroeconomics (e.g., Woodford, 2003). Moreover, many researchers believe that monetary policy has improved over time. In particular, the post-1982 decline in the volatility of output and inflation (the great moderation) is an outcome of changing monetary policy. However, this belief is a matter of active debate in the literature. Earlier studies (e.g., Clarida et al., 2000) assume a break point and find different reactions to expected inflation in the interest rate rules that are estimated before and after the break. More recent work (e.g., Sims and Zha, 2006) explicitly models regime changes in monetary policy and in the volatility of exogenous shocks and finds that, most likely, the regimes affected the economy via the changing shocks to the private sector. More generally, it is of the utmost importance to describe the forces that shape fluctuations in the business cycle. Time-varying volatility of shocks and monetary policy are two plausible mechanisms that can generate the aggregate volatility. Thus, understanding their interaction transcends the specific task of explaining the great moderation.

This paper contributes to the debate on the sources of aggregate fluctuations by arguing that monetary policy regimes may not be estimated precisely if one uses information from the short interest rate only. We propose to incorporate the information from the cross-section of yields, which by its nature is forward-looking and thereby reflects market-based expectations of the monetary policy that will be implemented in the future. We incorporate this information by proposing a novel no-arbitrage term structure model, which allows for regime shifts in the monetary policy and in the shocks to the private sector. We show, via a Monte Carlo analysis, that the yields of several maturities can be helpful in identifying monetary policy. We find that US monetary policy can be characterized as switching between active and passive regimes, judging by the differential response of the interest rate to expected inflation.
The finance literature has produced a number of important contributions to yield curve modeling with regime shifts. However, all of the existing finance models are reduced-form models. This means that one cannot isolate the regime switches in the structural shocks to the economy from the regime switches in the monetary policy. For this reason, we complement the traditional no-arbitrage setup with structural assumptions.

We impose these assumptions in the spirit of the structural VAR literature. That is, we explicitly posit a monetary policy reaction function and the dynamics of the macro economy. However, our specification is silent about investors' preferences and how they are connected to the model's parameters. The advantage of this approach is that the model is less restrictive than explicit structural models and thus allows for a greater degree of realism.

We dispense with the latent factors that are traditionally encountered in finance models and rely only on three observable variables: inflation, output, and the short interest rate. The economy’s (inflation and output) behavior is driven by past, current, and expected future values of inflation and output. We assume that the short interest rate is the monetary policy instrument. Similar to forward-looking Taylor rules, the monetary policy responds to expected future inflation and current output. We also allow for some degree of policy inertia by positing a response to the past interest rate.

We allow for three regime variables in our model. The first shifts the volatilities of exogenous inflation and output shocks. The second switches the parameters in the systematic monetary policy reaction function modeled as a forward-looking interest rate rule. The third affects the volatility of the monetary policy shock.

We propose a new approximate solution, which we use macro data only, and estimate models in which structural contributions vary. The topic of our paper bridges two strands of the macro literature. One strand is concerned with understanding the role of the time-varying volatility of exogenous shocks via a-a vis time-varying monetary policy in generating fluctuations in the business cycle. Researchers of this topic allow for time-varying volatility of shocks, use macro data only, and estimate models in which structural restrictions are imposed with varying degrees of severity. The conclusions vary. Cogley and Sargent (2005) find evidence of varying persistence of inflation and conclude that monetary policy was

1 Latent factor regime-switching no-arbitrage models of term structure are represented by the works of Bansal and Zhou (2002), Bansal et al. (2004) and Dai et al. (2007), among others. Ang et al. (2008) and Evans (2003) develop regime-switching models to study the term structure of real interest rates and inflation premia by combining the latent and macroeconomic factors.

2 This solution is consistent with the view that if policy had changed in the past, rational economic agents would form expectations about future changes in policy and act accordingly.

3 See, e.g., Ang et al. (2008) and Dai et al. (2007) for examples of parameterizations that lead to analytical expressions for bond prices.

4 See, e.g., Bansal and Zhou (2002) for an example of an approximate solution based on log-linearization.
changing as well. Primiceri (2005) finds large oscillations in the monetary policy, which have little effect on the real economy. Sims and Zha (2006) find no evidence of changing monetary policy. Fernandez-Villaverde et al. (2010) find evidence of changing monetary policy but conclude that the changes had little effect on the economy.

The second strand of the literature uses information in the yield curve to inform about a potential misspecification in macro models that are not necessarily concerned with changing monetary policy. For example, Rudebusch (2002) uses long yields to distinguish between interest rate smoothing and persistent monetary shocks when various versions of the Taylor rule are used. Gürkaynak et al. (2005) use models of the business cycle to derive the reaction of long-term forward rates to macroeconomic surprises from business cycle models. The authors reject these models on the basis of observed reactions of forward rates. These papers do not specify a formal term structure model for their analyses.

In the spirit of the last two papers cited above, we use a term structure model in an attempt to bring evidence from the yield curve to bear on the issues raised in the first strand of the literature. Fuhrer (1996) is an early work that studies policy shifts using the yield curve. Fuhrer replicates the violations of expectations hypothesis by assuming constant risk premia and changes in volatility. The variables \( g \) (2.1) and \( s \) are mutually independent. Stochastic innovations \( \epsilon_i \) and \( \epsilon_t \) are assumed to be i.i.d. standard normal variables. In principle, the inflation shock could be conditionally correlated with the output shock. However, we do not allow for such correlation because in practice it is hard to distinguish it from regime changes.\(^6\) Thus, \( \epsilon_i \) and \( \epsilon_t \) are mutually independent.

Assuming that the short interest rate is the instrument of monetary policy, Eq. (2.3) represents a monetary policy function.\(^7\) We borrow the specification of the monetary policy reaction function (2.3) from a single-regime baseline model of Clarida et al. (2000). This function has the form of a forward-looking Taylor rule that allows for some degree of monetary policy inertia, which is captured by parameter \( \rho \). The first three terms in (2.3) are a systematic part of the monetary policy, which switches with regime \( s^2 \). The monetary policy shock, interpreted as a random outcome of the Fed decision-making process, \( \sigma_i (s^i_t) \epsilon_i^t \), is driven by its own regime \( s^2 \), which affects the volatility of the policy shock. When the volatility \( \sigma_i (s^i) \) is high, the Fed is more willing to deviate from the systematic rule. The stochastic innovation \( \epsilon_i^t \) is modeled as an i.i.d. standard normal variable. Given that the exogenous policy shock is independent of the rest of the economy, \( s^i \) is not correlated with either \( \epsilon_i^t \) or \( \epsilon_t \).

As emphasized by Sims and Zha (2006) and Cogley and Sargent (2005), it is essential to account for the stochastic volatility of exogenous shocks when trying to identify shifts in monetary policy, because a specification of constant volatility may easily lead to spurious instabilities in the drift term. Following Sims and Zha (2006) and Ang et al. (2008), we allow the drift and volatility terms to be driven by their own regime variables. For reasons of tractability, the regime variables \( s^1, s^m \) and \( s^2 \) are assumed to be mutually independent.

2.2. Rational expectations solution

We assume that the private sector and the Fed have the same information when forming their expectations about future values of the state variables. In addition, both the Fed and private sector

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\(^6\) We tried to estimate a more general specification that would allow for the conditional correlation of the shocks. However, empirically, it is difficult to separate the effect of this correlation from the unconditional correlation that is due to changes in regimes. This prompted us to restrict the conditional correlation of shocks to zero.

\(^7\) One might argue that during the monetary experiment of 1979–1982 the Fed explicitly targeted the unborrowed reserves and that, therefore, the funds rate was not an acceptable indicator of the stance towards monetary policy in that period. However, many authors provide evidence that the funds rate remained a valid, albeit imperfect, measure of the monetary policy (for example, Cook, 1989; Romer and Romer, 2004).
know the current realizations of regimes.8 Finally, to achieve the tractability of solutions, the probabilities of regime changes are assumed to be constant and, therefore, independent of the state variable \( x_t \).

Under the above assumptions, it can be shown that the rational expectations solution of (2.1)–(2.3) where agents form the expectations of future state variables taking into account the future shifts in regimes is given by the following regime-switching vector autoregressive process:

\[
 x_t = \mu(S_t) + \Phi(S_t)x_{t-1} + \Sigma(S_t)\epsilon_t
\]

where \( \epsilon_t = (\epsilon_{t1}^g, \epsilon_{t2}^g, \epsilon_{t3}^y) \) and reduced form parameters \( \mu, \Phi \) and \( \Sigma \) are nonlinear functions of the parameters of the original model (2.1)–(2.3). The Online Appendix discusses the existence and uniqueness conditions for the above problem and suggests a numerical method for finding the parameters for the reduced form. The Online Code available at [http://dx.doi.org/10.1016/j.jeconom.2013.01.002](http://dx.doi.org/10.1016/j.jeconom.2013.01.002) provides the implementation algorithm.

### 2.3. Structural vs reduced-form representations

Given that our model can be cast as a regime-switching VAR with nonlinear parameter constraints, one might think that a better empirical approach would be to estimate a more flexible unrestricted VAR in order to avoid the potential misspecification in the model (2.1)–(2.3). However, if the economic agents’ behavior is forward-looking, as in the model (2.1)–(2.3), the reduced form parameters will change whenever any one of the regime variables changes. For example, it is not possible to attribute a shift in the conditional volatility of the reduced-form state dynamics to either shifts in monetary policy or changes in the volatilities of the exogenous shocks without making extra assumptions.

To gain a better intuition regarding the last point, we refer to the analytic solution (2.7)–(2.10) of the single-regime model. For example, the covariance matrix of the rational expectations solution \( \Sigma \) is determined by the properties of both conditional mean and variance of the structural equation (2.6). Thus, a shift in \( \Sigma \) could be coming from either \( \theta_0, \theta_1, \Gamma \) or any combination of these.

By distinguishing private sector, monetary policy, and volatilities of exogenous shocks explicitly in (2.1)–(2.3), we effectively impose the requisite identification assumptions on the reduced-form representation (2.5). This structural identification is what distinguishes our approach from the existing term structure models. We can explicitly separate the effects of changes in the monetary policy from the effects of changes in shocks on the yield curve.

Ideally, we would have liked to have derived explicitly the dynamic equations that describe the economy from fundamental microeconomic principles in a general equilibrium framework.9 However, for the set of the state variables used in this paper, the existing general equilibrium studies were not able to produce market prices of risk flexible enough to fit the yield curve accurately. We think that our approach is sufficient for distinguishing between the private sector and monetary policy blocks of equations and that it is an empirically relevant and internally consistent alternative to a general equilibrium model.

A natural concern is that the structural restrictions may make the model inflexible in comparison with reduced-form formulations. As a result, some important moments of the data will not be matched. Ultimately, this is an empirical question, which we will investigate in due course. However, we would like to offer some ex ante observations about the potential flexibility of our model.

Continuing with our single-regime model as a motivation, we recall that changes in the covariance matrix of the rational expectations solution could be driven by changes in the drift and volatility parameters. Each of these parameters are allowed to have only two regimes in our model. However, their interaction produces eight possible regimes: two for each of the changes in monetary policy (2.3), changes in volatility of policy shocks (2.3), and changes in the volatility of private-sector shocks (2.1), (2.2). Thus, a reduced-form representation of our model (2.5) is potentially more flexible than any extant reduced-form regime-switching term structure models. Just to name a few recent examples, Ang et al. (2008) have six regimes in the most flexible version of their model, and Dai et al. (2007) use two regimes.

Campbell et al. (2010) use a separate state variable to model stochastic volatility of the spot real interest rate and inflation (thereby generating stochastic covariance between the two). Of course, using a state variable is a more flexible modeling approach than using regimes. However, our covariance matrix allows not only for multistate volatility, but also for multistate covariance between all the states in our model. Thus, qualitatively, our model is capable of capturing the same effects. Given that we are interested in policy regimes, we believe that regime switches is a more appropriate framework for this paper.

### 2.4. Market prices of risk

In order to be able to value bonds, we complete the model with a stochastic discount factor \( M_{t,t+1} \):

\[
 \log M_{t,t+1} = -\tau_t - \frac{1}{2} \Lambda_{t,t+1} - \Lambda_{t,t+1}^\prime f_{t+1}.
\]

The market price of risk \( \Lambda_{t,t+1} \) is specified as the product of the volatility of the state variable \( x_t \) and the time-varying vector \( \Pi(x_t) \):

\[
 \Lambda_{t,t+1} = \Sigma(S_{t+1})\Pi(x_t).
\]

This specification recognizes the fact that investors require greater compensation for holding bonds in a more volatile economic environment. As we discuss in the Online Appendix, time-varying parameters \( \Pi(x_t) \) could be related, in a reduced-form sense, to the attitude towards risk on the part of the investors. Therefore, taking some liberties with language, we will refer to \( \Pi(x_t) \) as “preferences” or “risk aversion.”

Following Duffee (2002) and Dai et al. (2007), we assume an essentially affine structure of “preferences” \( \Pi(x_t) \):

\[
 \Pi(x_t) = \Pi_0 + \Pi_x x_t.
\]

The “preferences” do not depend explicitly on the regimes, which is consistent with our assumption that the dynamics of the private sector are stable.11 Indeed, in a general equilibrium model, the parameters in equations governing the private sector (2.1), (2.2) would be functions of the agents’ preferences. For the same reason, Dai et al. (2007) note that \( \Lambda_{t,t+1} \) cannot be straightforwardly interpreted as market prices of risk because \( \Lambda_{t,t+1} \) are not in the investors’ information set at time \( t \). As Eq. (2.5) and our discussion of Eq. (2.11) in the Online Appendix show, our specific timing is an outcome of our structural formulation. We attach a label “market prices of risk” to \( \Lambda_{t,t+1} \), but do not attempt to interpret these parameters directly.

This assumption by no means implies that the agents’ preferences cannot vary over time. In fact, it is exactly the time-varying effect that is captured by the essentially affine specification in (2.13).

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8 These assumptions are clearly not innocuous. The importance of imperfect knowledge and learning has been emphasized by Sargent (1999), Schorfheide (2005) and Primiceri (2006) among many others.

9 Woodford (2003) provides a comprehensive exposition of this subject. Bekker et al. (2010) propose a single-regime “New Keynesian” general equilibrium model that is based on a number of observable and unobservable state variables in order to study the term structure of interest rates.

10 Dai et al. (2007) propose that \( \Lambda_{t,t+1} \) cannot be straightforwardly interpreted as market prices of risk because \( \Lambda_{t,t+1} \) are not in the investors’ information set at time \( t \). As Eq. (2.5) and our discussion of Eq. (2.11) in the Online Appendix show, our specific timing is an outcome of our structural formulation. We attach a label “market prices of risk” to \( \Lambda_{t,t+1} \), but do not attempt to interpret these parameters directly.

11 This assumption by no means implies that the agents’ preferences cannot vary over time. In fact, it is exactly the time-varying effect that is captured by the essentially affine specification in (2.13).
the changes in the regimes themselves are not priced in this paper.\footnote{Dai et al. (2007) argue, in a reduced-form model, that allowing the risk of changing regimes to be priced may substantially increase the model's ability to fit the data. In their setup, investors require a premium for possible changes of future regimes even if there is no uncertainty about the state variables. This assumption means that the agents' preferences are explicit functions of the regime variables. Ang et al. (2011) make similar points in the context of a model with drifting policy and reduced-form representation of the private sector with constant parameters. Such an extension is not possible with our structural assumptions about the constant parameters in the private-sector equations.}

This specification of the stochastic discount factor is commonly referred to as “no-arbitrage restrictions” in the finance literature. For our purposes, the main attraction of these restrictions is the ability to translate, in an internally consistent manner, the expectations about monetary policy that are implied by our model \((2.1)–(2.3)\) into market expectations that are reflected in the yield curve. As we argue in what follows, bringing the information from the yield curve is crucial for understanding the monetary policy.

The flexible specification of the risk premia may cause concern about potential overparameterization. We took extra care to mitigate such concern. We impose the following restrictions. (i) All factors driving risk premia are observable; standard term-structure models use at least two latent factors, which leads to enormous flexibility in the risk premia; observed factors tie our hands in important ways. (ii) We implicitly assume that the private sector preferences remain constant, which further reduces the number of free parameters that we can use in fitting of the yield curve. (iii) Upon estimation, we carefully inspect the significance of the parameters controlling the risk premia.

2.5. Bond valuation

Having defined \(M_{t,T+1}\) we also introduce an \(n\)-period stochastic discount factor as

\[
M_{t,1+n} = \prod_{i=1}^{n} M_{t+i-1, t+i},
\]

(2.14)

Then the price of a zero-coupon bond with maturity \(n\) can be found as

\[
B_t^n(x_t, S_t) = E[M_{t, t+n} | x_t, S_t].
\]

(2.15)

The bond prices do not have a closed-form solution. We deviate from the standard strategy of computing an analytical approximate solution that is based on the log-linearization. The Online Appendix describes our approximate pricing method and provides evidence of its accuracy.

2.6. Empirical approach

We use quarterly series of macro and bond data from 1970 to 2008. The annual log difference of an implicit price deflator was used as a proxy for inflation. We use a linearly detrended log of real per capita GDP as a proxy for detrended real output. Both the price deflator and GDP series are obtained from the FRED database. Our yields data are an unsmoothed Fama–Bliss series.\footnote{We are grateful to Robert Bliss for providing us with the data.} Four different maturities were used: 3 months and 2, 5, and 10 years.

The macro variables are assumed to be observed without errors. One might argue against this assumption, given that inflation and GDP are not perfectly observed. However, our model is not grounded in equilibrium foundation and does not require observations of the true inflation and output. We can interpret our model as a description of the specific macro variables that we used.

The theoretical yield of the 3-month yield computed from \((2.15)\) coincides with the short rate because of the quarterly frequency of the data. Therefore, it is practical to assume that this yield is observed without any measurement error, so that the state vector \(x_t\) is observed exactly. It is assumed that the other yields were measured with errors. We choose the simplest correlation structure of the yield measurement errors: all errors are independent and identically normally distributed with a standard deviation of \(\sigma_y\). The rationale for this specification is to put as much pressure on the model as possible to fit the yield curve.

Our estimation method is maximum likelihood. For any given set of “structural” parameters from model \((2.1)–(2.3)\), we compute reduced-form parameters \(\mu, \Phi, \Sigma\), as in \((2.5)\). The latter parameters and “risk aversion” coefficients \(\Pi_0\) and \(\Pi_t\) are then used to compute the bond prices and construct the likelihood function. The details of the procedure are provided in the Online Appendix.

Consistent with previous studies on regime-switching term structure, we find that the means of state variables are identified poorly. Following Ang et al. (2008) and Dai et al. (2007), we pin down these parameters to match the long-run means of the state variables in the data. The Online Appendix shows how to compute the long-run means of the state variables in our model.

Because, as is well-known, regime-switching models have many local optima, it is necessary to search for the global optimum carefully. We use the following optimization approach. First, we select starting values by generating 1,000,000 Sobol points from a range of reasonable parameter values.\footnote{The Sobol sequence is a deterministic sequence that appears to be random. The use of the Sobol sequence instead of random numbers avoids the unpleasant clustering property of the conventional Monte-Carlo approach. See Glasserman (2003) for the exact definition of the Sobol sequence.} Second, we choose 10,000 points that lead to the largest likelihood values. Finally, starting from each of these points, we run local optimization and select the best result.

Because both macroeconomic and yield data are highly persistent, the asymptotic inference theory is likely to be unreliable. Therefore, following Conley et al. (1997), we implement a parametric bootstrap approach. We simulate 1000 data paths from the estimated model and reestimate the model along each path. This approach yields the finite sample distribution of the parameters that is used to construct the confidence bounds.

2.7. The role of bonds in estimating monetary policy

Understanding how bonds contribute to estimating monetary policy in our model consists of two steps. First, it is necessary to establish whether the Taylor rule \((2.3)\) coefficients are identified. Cochrane (2011) makes a forceful argument that structural restrictions do not necessarily entail the identification of all structural parameters. This may well be so, but, as we argue, in our model structural parameters pertaining to the dynamics of the state variables are identified locally. Second, theoretical identification does not imply that parameters will be well-estimated in practice. This will depend on the data used in estimation and the sensitivity of the corresponding likelihood function to parameters of interest. Therefore, we illustrate how adding bonds increases the precision and reduces finite-sample bias of the estimates.

First, our model \((2.1)–(2.3)\) is identified on the basis of observed output, inflation and spot nominal interest rate alone. In other words, one can estimate a reduced-form restricted VAR \((2.5)\), and then recover the structural parameters from reduced-form ones. It is difficult to prove this claim analytically, given the complexity of our model and the lack of analytic rational expectations solution of our model. The Online Appendix outlines our numerical strategy to verify the local identification of parameters. We find that the model is fully identified locally, at least with respect to the estimated parameter values.
This result raises a question as to whether a term structure model and bond prices are needed at all. Herein, we argue that adding bonds produces more precise and less biased (in a finite samples) estimates of the loadings in the Taylor rule. The Online Appendix provides an ex ante argument of why this would be the case on the basis of a simple example. We provide an ex post analysis of this issue after estimating our model. Specifically, to study the information content of long-term yields, we consider a smaller dataset that consists of inflation, detrended output, and a 3-month yield only. We refer to a model estimated on this set as a “short-rate model”, or SRM. The same model estimated on the set that includes yields in addition to the macro-variables is referred to as a “term-structure model”, or TSM.

3. Results

The Online Appendix provides a goodness-of-fit analysis of the TSM. The overall conclusion is that one can trust the implications of the model, because it is sufficiently realistic. We analyze the model properties in Sections 3.1 and 3.2. Then, in Section 3.3, we investigate the issue of whether the yield curve contains information that is useful for identifying monetary policies. Finally, in Section 3.4, we present the counterfactual policy analysis.

3.1. The model properties

3.1.1. Estimates of the state dynamics

The parameter estimates reflecting the dynamics of the state variables are displayed in Table 1. The parameter values are scaled so that they correspond to annual changes in macro variables and yields, measured in percentage points. For example, volatilities \( \sigma_i, i = g, r, r, r \), are reported as \( \sigma_i / \sqrt{ \Delta } \) where \( \Delta = 1/4 \). In this section, we focus on the TSM version.

The constant parameter estimates in the equations for the private sector are generally consistent with single-regime New-Keynesian term-structure models (e.g., Bekoet al., 2010; Hodahl et al., 2006; Rudebusch and Wu, 2008). The degrees of forward lookingness of inflation and output, \( \mu_r \) and \( \mu_g \), respectively, are both approximately equal to 0.5. This value is similar to Bekoet al. (2010), but is higher than that found by other authors. The sensitivity of inflation to the output \( \delta \) is small but significant, which is consistent with Rudebusch and Wu (2008). The sensitivity of output to the real rate, \( \phi \), is small but significant, as is the case in much of the macroeconomic literature. Parameters \( m_r, \mu_r, m_g, \mu_g \) are insignificantly different from zero. Our model (2.1)–(2.3) implies that \( \mu_r = -\delta E(g) \) and \( \mu_g = \phi (E(r) - E(\pi)) \). Therefore, the estimate of \( m_g \) is consistent with our use of detrended real output. The estimate of \( m_r \) is consistent with a small value of \( \phi \). In addition, the values of \( m_g \) and \( \phi \) imply that the long-run real rate is equal to \( 2\%\) (\( m_g / \phi \)), which is consistent with the classic Taylor rule and is right in the middle of the various estimates reported in the macro literature.

We see that in one state of the regime variable \( \xi_t \), the volatilities of exogenous shocks \( \sigma_g(1) = 1.06 \) and \( \sigma_r(1) = 0.56 \), which correspond to the output and inflation equations, respectively, are greater than the ones in the other regime, where \( \sigma_g(2) = 0.66 \) and \( \sigma_r(2) = 0.23 \). Therefore, we refer to the first state as a “high-volatility” regime.

The volatility \( \sigma_g(1) = 2.84 \) of the exogenous monetary policy shock in state 1 of \( \xi_t \) is greater than \( \sigma_g(2) = 1.41 \) in state 2. Thus, in the first state, which we call a “discretionary” regime, the Fed deviates significantly from the systematic interest rate rule. In the second state, the monetary authorities tend to follow the systematic rule more closely. We call this the “commitment” regime.

The regimes have very different properties. In one regime, the response to inflation \( \alpha(1) = 3.53 \) is greater than unity. In a single-regime framework, this condition is known to guarantee the uniqueness of the rational expectation solution of model (2.1)–(2.3) and to rule out non-fundamental equilibria. We call this state an “active” monetary regime, because of the strong reaction on the part of the Fed to one-quarter expected inflation. The other regime has a coefficient that is less than unity, \( \alpha(2) = 0.36 \). In a single-regime setup, this condition may lead the economy to be prone to non-fundamental sunspot fluctuations. Intuitively, if parameter \( \alpha \) is less than 1, the Fed reduces its real rate long-term target when expected inflation rises. A lower real interest rate will accelerate economic growth, which will result in higher inflation. Thus, expectations about high inflation are self-fulfilling. We refer to this state as a “passive” monetary regime.

We interpret the estimated response to expected inflation in the context of the findings reported by Clarida et al. (2000). These authors estimate a constant coefficient model similar to the one specified in this paper for pre- and post-1979 subsamples. For the pre-1979 (pre-Volcker) subsample, they found the response to inflation to be less than unity, while for post-1979 (Volcker and Greenspan) subsample the response turned out to be greater than unity. They argue that the fact that the response was less than 1 in the first subsample may indicate the effect of non-fundamental sunspot shocks, which could explain the high volatility of the macroeconomic environment in the pre-Volcker era.

This argument does not take into account the fact that economic agents may have expected the change from a passive regime to an active one. If this were the case, rational agents would have formed their expectations about inflation accordingly, thereby eliminating sunspot dynamic paths. Our model addresses this concern directly via the regime-switching framework. The rational expectations solution of our model incorporates explicitly the view that agents anticipate changes in the policy response. Thus, despite the switching of the monetary policy into the passive regime, our model has a unique rational expectations solution.

The values of parameters \( \beta(1) = 2.18 \) and \( \beta(2) = 1.27 \) suggest that the Fed reacted more aggressively to the real output in the active regime than in the passive one. We can also see that in the active regime, the degree of monetary policy inertia captured by parameter \( \rho(1) = 0.97 \) was higher than \( \rho(2) = 0.81 \) in the passive regime.

Due to the fact that our model specification is not derived from the micro fundamentals, our results are silent about “deep” parameters that connect investor’s preferences and state variables dynamics. In particular, we cannot provide an economic interpretation of our “preferences” parameters. Therefore, we simply display them in Table 2 for completeness. When the model was estimated initially, half of the parameters were insignificant. Given that no structure is imposed on the “preference” parameters, we decided to mitigate concerns about potential overfitting by restricting the insignificant parameters to zero and by re-estimating the model. The essential risk premia specification is warranted, nonetheless, because both the vector \( \Pi_0 \) and the matrix \( \Pi_t \) have statistically significant parameters.

3.1.2. Regime probabilities

The estimated probabilities for transitions between regimes are displayed in Table 3. The monetary regimes, \( \xi_t \), are the most persistent ones. For example, the probability that the active regime will continue is 98%. The monetary shocks regimes, \( \xi_t \), are the least persistent ones: the probability of staying in either the discretion or commitment regime is 75%. We can view the realizations of regimes in our sample by computing the smoothed regime probabilities. Fig. 1 displays the smoothed probabilities of the active, high-volatility, and discretionary regimes.
Table 1  
Parameter estimates. Dynamics of the state variables. The table reports parameter estimates for two versions of our model: \( g_t = m_{00} + (1 - \mu_p) r_{t-1} + \mu_\varphi \varphi t \) and \( \varphi t \). The TSM version is a no-arbitrage term structure model with independent regimes the volatilities of exogenous shocks, the systematic monetary policy, and the volatility of the monetary policy shock. This model is estimated with output, inflation, and a cross-section of yields. The SRM version is identical to TSM but is estimated without long-term yields using the short interest rate (3-month yield) only. The bootstrapped 95% confidence intervals are presented in parentheses.

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<tr>
<th></th>
<th>SRM</th>
<th>TSM</th>
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<tbody>
<tr>
<td></td>
<td>( m_0 \times 10^3 )</td>
<td>( m_\varphi )</td>
</tr>
<tr>
<td>Private sector</td>
<td>0.00</td>
<td>1.79 (−1.08, 4.20)</td>
</tr>
<tr>
<td>Monetary policy</td>
<td>0.00</td>
<td>−0.19 (−0.34, 0.08)</td>
</tr>
</tbody>
</table>

Table 2  
Parameter estimates. Risk premia. The table reports the risk premia estimates for TSM. SRM uses the short rate only for estimation and, therefore, risk premia cannot be estimated for this version of our model. The bootstrapped 95% confidence intervals are presented in parentheses. Parameter values, which do not have confidence bounds, were restricted to zero due to their lack of significance at the first estimation.

<table>
<thead>
<tr>
<th></th>
<th>( \Pi_0 )</th>
<th>( \Pi_\varphi )</th>
<th>( \gamma )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>3.65 (1.10, 9.10)</td>
<td>0.52 (0.05, 1.98)</td>
<td>0.00 (0.00, 0.00)</td>
<td>−0.34 (−0.96, −0.09)</td>
</tr>
<tr>
<td>( \pi )</td>
<td>0.00 (0.00, 0.00)</td>
<td>1.27 (0.04, 4.70)</td>
<td>0.00 (0.00, 0.00)</td>
<td>0.52 (0.03, 1.42)</td>
</tr>
<tr>
<td>r</td>
<td>−0.32 (−0.55, −0.13)</td>
<td>0.00 (0.00, 0.00)</td>
<td>−0.02 (−0.02, −0.02)</td>
<td>−0.04 (−0.04, −0.01)</td>
</tr>
</tbody>
</table>

Table 3  
Parameter estimates. Transition probabilities. The table reports the estimates of the transition probabilities for two models. TSM is a no-arbitrage term structure model with independent regimes the volatilities of exogenous shocks, the systematic monetary policy, and the volatility of the monetary policy shock. This model is estimated with output, inflation, and a cross-section of yields. SRM is identical to TSM but estimated without long-term yields using the short interest rate (3-month yield) only. The bootstrapped 95% confidence intervals are presented in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>TSM</th>
<th>SRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic monetary policy regime variable ( \varphi t )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active</td>
<td>98.21 (97.19, 99.56)</td>
<td>69.65 (56.61, 81.99)</td>
</tr>
<tr>
<td>Passive</td>
<td>9.69 (4.50, 18.40)</td>
<td>72.57 (58.70, 91.66)</td>
</tr>
<tr>
<td>Low vol</td>
<td>94.34 (82.15, 99.79)</td>
<td>98.72 (76.67, 99.68)</td>
</tr>
<tr>
<td>High vol</td>
<td>5.66 (0.80, 17.96)</td>
<td>1.28 (0.22, 20.90)</td>
</tr>
<tr>
<td>Passive</td>
<td>4.97 (1.50, 8.83)</td>
<td>1.66 (1.02, 15.30)</td>
</tr>
<tr>
<td>Low vol</td>
<td>95.03 (91.03, 98.34)</td>
<td>98.34 (83.76, 99.12)</td>
</tr>
<tr>
<td>High vol</td>
<td>56.61 (14.50, 29.99)</td>
<td>90.55 (67.38, 97.25)</td>
</tr>
<tr>
<td>Volatility of monetary policy shock regime variable ( \varphi t )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discretion</td>
<td>78.66 (67.76, 83.30)</td>
<td>90.55 (67.38, 97.25)</td>
</tr>
<tr>
<td>Commitment</td>
<td>17.74 (12.70, 26.10)</td>
<td>7.47 (2.70, 21.73)</td>
</tr>
</tbody>
</table>
The active regime appeared in the 1970s and during the Volcker disinflation period after the end of the monetary policy experiment. As to the Greenspan tenure as Chairman of the Fed, the active regime prevailed from 1991 to 1995 and was implemented from 2002 to the end of the sample period. The period from 1973 to 1975, the monetary experiment of 1979–1982, the period from 1988 to 1991, the internet bubble 1995–2001 period, and the period from 2005 to 2007 are characterized by the passive regime. The discretionary regime appeared sporadically throughout the sample. These regimes are well-identified because despite the frequent changes in regime, there is little uncertainty as to whether or not a regime is discretionary: the smoothed regime probabilities are always clearly 0 or 1.

We can see that the volatility of exogenous shocks was high throughout the 1970s (during which major oil shocks occurred), during the monetary policy experiment, in 1998 (Russian default and the LTCM collapse), in 2000–2001 (the burst of the Nasdaq bubble and the terrorist attack of September 11th), and in 2004–2008 (oil price shock and the credit crisis). Note that all the recessions except the one of 1991 were associated with high-volatility regimes.

### 3.2. Implications for a reduced-form version of the model

We now connect our model to existing reduced-form models by focusing on the reduced-form implications of the estimates. The first three panels of Fig. 2 display time series of volatilities of the state variables that are implied by the reduced-from representation (2.5). The volatilities are constructed by assuming no statistical uncertainty about which one of the eight regimes prevails at each time and by computing the volatility in each regime. The result is represented by dashed black lines. To get a better sense of the trend, we also compute an eight-quarter moving average of the series. The moving average is represented by solid blue lines.

The volatility pattern indicates that volatilities are not tied to any specific structural regime, e.g., a high-volatility regime. Indeed, as highlighted in Section 2.3, volatilities represent a convolution of parameters that is determined by different regimes. This feature generates richness in the volatility dynamics. There is a commonality in the volatility of output and inflation: both decline from 1980 to 2005 with some transient spikes along the way. The most...
recent and the largest spike from 2005 to 2008 coincides in time with the oil shock (until late 2007) that overlapped with the onset of the credit crisis (from early 2007). In contrast to the macro variables, the volatility of the short interest rate has a clear procyclical component. There is a noticeable downward trend over the full sample. The pattern for volatility in the interest rate is similar to the one reported in Cogley et al. (2010).

The final panel of Fig. 2 displays the correlation between the short interest rate and inflation to illustrate the time variation in correlations between the state variables. Despite the fact that the structural form of the model assumes independent shocks to the short rate and inflation, these two variables are correlated. Moreover, the pattern for correlations in the time series shows a richness that is comparable to the one assumed in Cogley et al. (2010). The correlation varies between 0.3 and −0.1. It is countercyclical and was negative in the mid-1980s and mid-1990s.

The reduced-form version of the model connects with Cogley and Sargent (2005) as well. These authors allow for varying volatility of shocks and find evidence of varying persistence of inflation after controlling for the volatility. They conclude on the basis of this evidence that monetary policy was also changing. We follow the Cogley and Sargent strategy in constructing a measure of inflation persistence that is free of the effect of varying volatility. To motivate this measure, consider an AR(1) model of inflation with persistence $\phi$ and conditional volatility $\sigma$. The persistence of inflation can be recovered from the unconditional variance of inflation, $\sigma^2$. Indeed, $\sigma^2 = \phi^2/(1 - \phi^2)$. Therefore, $\phi = \sqrt{1 - (\sigma^2/\phi^2)}^{-1}$. This expression of persistence is useful in our case because we have two complications that make it difficult to assess changes in persistence of inflation. First, matrix $\Phi$ in (2.5) has off-diagonal elements, so it is difficult to attribute persistence to a particular factor. Second, both $\Phi$ and $\Sigma$ change with regimes.

We compute the unconditional variance of inflation in each of the eight possible regimes:

$$
\text{vec}(\Sigma(S_t)) = (I_9 - \Phi(S_t) \otimes \Phi(S_t))^{-1} \text{vec}(\Sigma(S_t) \Sigma'(S_t)).
$$

Next, we construct a ratio of the unconditional variance of inflation to the conditional variance of inflation to control for the effect of variation in volatility:

$$
\mathcal{R}(S_t) = \frac{\text{vec}(\Sigma(S_t))}{\text{vec}(\Sigma(S_t) \Sigma'(S_t))}.
$$

where $e_2$ is a vector of zeros with a one in the second position. Finally, our measure of persistence is

$$
\Upsilon(S_t) = \sqrt{1 - \mathcal{R}^{-1}(S_t)}.
$$

The rationale for such a measure is that if there are no regimes and $x_t = \pi_t$ is a scalar, then $\Upsilon$ recovers the persistence $\phi$. Thus, the measure generalizes the natural concept of persistence to a vector and regime-changing settings.

Fig. 3 displays the time series of $\Upsilon$. Consistent with Cogley and Sargent (2005), we observe a decline in the persistence of inflation. It is interesting that inflation is less persistent during the periods of both active and passive monetary policy (cf. Fig. 1). This suggests that monetary policy affects fluctuations in the business cycle, not
by merely implementing one policy rather than another, but by implementing the “right” regime at the “right” time. We return to this issue in later sections when we investigate the structural implications of our model.

3.3. Is the term structure important for identifying monetary regimes?

3.3.1. The short-rate model

We can see from Fig. 1 that TSM delivers well-identified monetary regimes: at any particular time, the smoothed probability of the regime is close to either 0 or 1. Does the term structure help in identifying the regimes? Intuitively, it does, because the long-term yields contain information about expected monetary policy and, in particular, about the probabilities of future monetary regimes.

To address this issue more formally, we estimate SRM, that is, model (2.1)–(2.3), with the same specification of regime variables as in TSM but with the smaller dataset of inflation, output, and the short rate only. Because yields are not used, the “preference” parameters are not identified and, therefore, cannot be estimated.

Table 1 reports the parameter estimates for this model. As in TSM, there are two systematic monetary regimes. Using the monetary policy response to the one-quarter expected inflation as a basis, we can classify the regimes as active and passive. There are still two regimes for the volatility of exogenous shocks (high and low) and two regimes for the volatility of policy shocks (discretion and commitment).

Fig. 4 shows the smoothed probabilities of the regimes for the short-rate model. We see that the high-volatility regime is very similar to the one obtained from the term structure model: the volatility was high in the 1970s and low afterwards. The transition probability matrices in Table 3 and Figs. 1 and 4 indicate that the systematic monetary regimes that are obtained from the SRM are much less persistent than those that are obtained from the TSM. In addition, in contrast to the term structure model, where the systematic regime is well-defined, the probability of the active regime from SRM hovers around 0.5 in many subperiods.

Given this indeterminacy of the active regime, it is easy to see how a more parsimonious model, one that does not allow for changes in monetary regime, could be preferred to SRM. This observation is consistent with the conclusions reached by Sims and Zha (2006) in a regime-switching model estimated without the yield curve. They find that a model with a best fit allows for shifts in disturbances only.

3.3.2. Informational advantage of using the yield curve

The preceding subsection demonstrated that using the yield curve for estimation leads to very different conclusions about the historical monetary policy regimes. However, because the true monetary policy is unknown, we cannot evaluate the informativeness of the yield curve in quantitative terms. In order to address this issue, we performed the following simulation exercise. We simulated 1000 paths of data from the estimated term-structure model TSM. Then, we estimated both TSM and SRM along each path. For every simulated data sample, we computed the bias

$$\text{MSE} = \frac{1}{T} \sum_{t=1}^{T} (\hat{Q}(t) - Q(t))^2$$

of the smoothed probability \(\hat{Q}(t)\) of the regime from the known simulated regime probability \(Q(t)\) (equal to either 0 or 1 at each point of time) for both models and constructed the ratio of these biases:

$$R = \frac{\text{MSE}[SRM]}{\text{MSE}[TSM]}$$

This procedure yields a finite sample distribution of the ratio \(R\). If the yield curve does not contain information about the regimes in addition to that provided by the state variables, the ratio \(R\) must be equal to 1.

Table 4 reports 95% confidence bounds of \(R\) for all the three regime variables of our model. We can see that these bounds lie above 1. The bias of the systematic monetary regime that is obtained from the TSM is, on average, 20 times smaller than that given by the SRM. We conclude that the yield curve and no-arbitrage restrictions are instrumental in identifying the monetary regimes.

3.4. Counterfactual policy analysis

Given that our structural identification approach allows us to estimate parameters corresponding to all eight regimes, we can perform a model-based analysis of the effects of monetary regimes vis-à-vis trends in exogenous volatility. For a given combination of regimes, e.g., active monetary policy with discretionary shocks during high-volatility macro shocks, we can compute impulse responses. This approach ignores intentionally the possibility of a future change in regime. As a result, by comparing such impulse responses across the regime triples, that is, by performing counterfactual policy analysis, we can gauge what would have happened if the Fed had continued to implement the same policy, or if the private sector had never experienced changes in shocks. Alternatively, we can perform a time-series counterfactual analysis. In this case, we would retain the shocks \(\epsilon_t\) that were realized in the economy and change one of the regimes, say active monetary policy, to an alternative, for example, passive monetary policy. Such a hypothetical exercise allows to assess the importance of the exercised policy conditional on the specific historical experiences.

3.4.1. Counterfactual impulse responses

Fig. 5 shows the impulse-response functions of the state variables in response to one-standard-deviation shocks in state
variables themselves for TSM. The rightmost column of the panels shows the outcomes of the monetary policy shocks. These outcomes depend on the volatility of the policy shock and the stance of the systematic monetary policy, which determines the transmission of the shocks. However, they are independent of the volatility of exogenous shocks.

The observed change in the monetary transmission mechanism is due mainly to a change in the monetary policy. Indeed, there is almost no difference between the discretion and commitment regimes when the policy is passive (thin lines). When the policy is active (thick lines) the response is not identical, but qualitatively similar across the policy shock regimes. Output initially declines, but then increases in the long run. Inflation declines. Consistent with these changes in the private sector, the short rate initially increases, but then gradually declines in the active regime. In fact, the magnitudes of these changes can be attributed almost entirely to the implementation of the active monetary policy, because the response when the passive policy is implemented is close to zero (except for the brief spike in the short rate). The effect of a policy shock on the macroeconomy is stronger under discretion than under commitment, conditional on the systematic policy that is implemented. This result was to be expected, given that the discretionary policy is characterized by a higher volatility in the policy shock.

The two left columns of the panels in Fig. 5 depict the effects of the exogenous shocks. The volatility of the monetary policy shock does not affect the impulse responses in these plots. In the passive regime, the Fed reacts to an output shock strongly, by raising the short rate. However, this effect is transitory. In contrast, in the active regime, the rise in interest rates is more prolonged. As a result, the total effect on inflation and output is stronger in the active regime because both revert back to their initial state eventually. Similarly, when facing a shock in the inflation equation in the active regime, the Fed raises the short rate in a more aggressive and
protracted way compared to the reaction in the passive regime. In the high-volatility regime, the Fed always reacts more strongly to both types of shock than in the low-volatility regime.

We gauge the behavior of the yield curve in the different regimes by computing the impulse responses of the slope. The slope is defined as the 10-year yield minus the 3-month yield. As before, we condition the responses on a given combination of regimes. Accordingly, the bond prices are computed conditional on a path of a fixed regime $s$. Under this assumption, standard affine pricing is applied so that the yield of a bond with maturity $\tau$ is a linear function of the state vector $x_t$:

$$y(x_t, \tau, s) = a(\tau, s) + b(\tau, s)x_t.$$  \hfill (3.6)

Fig. 6 shows the impulse-response functions. Overall, the slope responses suggest that an active monetary policy steers the economy in a more stable way. Specifically, in comparison with the passive policy, the long-term yield rises more strongly than the short rate in response to all types of shock in the active regime. As a result of a monetary shock when the active policy is implemented, a monetary policy shock leads the short end of the term structure to rise more strongly than the long end. Hence, the slope becomes negative.

The difference in response to the monetary policy shocks across the regimes provides another insight into why TSM helps in identifying the changes in monetary regimes. SRM is simply incapable of gauging what happens with the slope. Therefore, we lose an important piece of information that differentiates between active and passive monetary regime.

As we saw in Fig. 5, the short rate increases in response to the output shock faster in the passive than in the active regime. This leads to a sharp decline of the slope in the passive regime. The short-rate adjustment is more gradual in the active regime, which results in output shock having a moderately positive effect on the slope. These observations, when combined with the fact that inflation declines in the active regime (Fig. 5), suggest that active monetary policy handle an economy with high inflation more effectively than the passive one. Inflation shock leads to a decline in the slope in the passive regime in the near term, which suggests expectations of recession. In contrast, the slope increases in the active regime. This is consistent with a more aggressive increase in the short rate and a faster decline in inflation during
the first 10 quarters, as shown in Fig. 5. Longer term, output falls more in the active regime, so agents expect a deeper recession in the active regime than in the passive regime. This is reflected in the declining slope in the active regime and increasing slope (past first 10 quarters) in the passive regime.

3.4.2. Counterfactual economies

Impulse responses reveal how the macro variables and yields respond to exogenous shocks across the different regimes. However, they do not provide a full picture, because analysts are typically interested in understanding how the different regimes interact with each other, given the realized sequence of shocks. Simulating counterfactual economies allows us to achieve precisely this goal.

In particular, the simulation of counterfactual economies allows us to make a contribution to the debate regarding the sources of the great moderation. Many analysts argue that beginning with the Volcker chairmanship of the Fed, the monetary policy has improved and has led to lower inflation and lower volatility of output. However, Stock and Watson (2003) attribute a large part of the reduced volatility to the reduced volatility of the exogenous macroeconomic shocks.

Most authors evaluate the effect of monetary policy by splitting the sample at 1982, which marks the end of monetary experiment. Evaluating averages and the standard deviations of inflation and output before and after this date has led many researchers to announce the arrival of the great moderation. Indeed, as Table 5 documents, the volatility of both inflation and output falls after 1982, average output increases, and average inflation declines. Should this moderation be attributed to the monetary policy?

To address this issue, we fix all the shocks as they were realized in our dataset. Similar to our estimation results, we assume that the high volatility of private sector shocks prevailed pre-1982, and then switched to low volatility afterwards. In addition, we commit ourselves to one of the four possible combinatory implementations of policies in response to shocks: active policy and discretion (AD), active policy and commitment (AC), passive policy and discretion (PD), and passive policy and commitment (PC).

Table 5 provides the evidence from counterfactual economies. The results imply that if any of the four monetary regimes was fixed throughout the entire sample, one would observe the same signs of moderation as in the actual data. Therefore, a large driver of the moderation is the change in the nature of the private sector shocks. This conclusion is consistent with Stock and Watson (2003).
Does this finding imply that monetary policy was irrelevant? To address this question we revisit the impulse responses and conduct additional counterfactual exercises. The analysis reveals a nuanced picture that suggests that monetary policy plays an important role, in addition to the “lucky” realizations of the exogenous shocks.

First, as we noted above, impulse responses reveal that monetary policy plays an important role, because the differences between responses are due mainly to the type of regime (active or passive) that is implemented. Second, the impulse responses in Fig. 5 highlight the asymmetries in the responses of output and inflation in the two types of monetary regime, depending on the type of shock. In the case of inflation shock, there is a trade-off between the behavior of the macro variables, depending on the monetary policy that is implemented. This is because output declines (an undesirable outcome) and inflation declines fast (a desirable outcome) in the active regime, whereas there are minimal changes in output (a desirable outcome) and inflation declines slowly (an undesirable outcome) in the passive regime. In the case of output shock, there is no trade-off, because there are almost no differences in the output behavior across the regimes, while inflation declines much faster in the active regime. Therefore, depending on the type of shock that is realized, either the active policy will dominate other strategies or there will be a non-trivial trade-off.

To investigate these effects in greater detail, we examine the counterfactual analysis of the time series once again. This time, in addition to fixing all the shocks as they were realized in our dataset, we also fix the realized regimes in volatility of the exogenous shocks (high or low). As before, we commit ourselves to one of the four possible policy–shock combinations: AD, AC, PD, or PC. By fixing one of the policies throughout the sample, but allowing for the realized exogenous shocks, we can evaluate whether the Fed had to face the trade-off discussed above.

To gauge how effective the Fed was in managing the trade-off, Table 5 compares the average inflation and output and the respective standard deviations from the full sample to those obtained from the counterfactual economies. The aforementioned trade-off in managing output and inflation is clear, because the average output is higher in the passive economies while the average inflation is lower in the active economies. Moreover, in the active economies, there is an additional trade-off between the discretionary and commitment regimes, because the discretionary regime leads to lower inflation and higher output at the cost of both variables being more volatile than in the commitment regime.

Evaluating the effect of the various policies on yields informs us about further differences between the regimes. Table 5 reports the averages and standard deviations of the short and long yields and Fig. 8 complements it with the time-series plots. The AD regime, which seemed to be attractive, given the average inflation and output, appears not likely to be implemented as the single prevailing regime because it generates highly volatile yields. In the PD regime, the averages and volatilities are very similar to those obtained from the counterfactual economies. The aforementioned trade-off in managing output and inflation is clear, because the average output is higher in the passive economies while the average inflation is lower in the active economies. Moreover, in the active economies, there is an additional trade-off between the discretionary and commitment regimes, because the discretionary regime leads to lower inflation and higher output at the cost of both variables being more volatile than in the commitment regime.

In the context of the post-1982 moderation, the realized inflation is, on average, lower and less volatile than inflation that results from the implementation of any of the individual regimes. The volatility of realized output is similar to that which occurs in the single-regime counterfactual economies. However, the average

Table 5
Sample statistics in the data and counterfactual economies. This table provides summary statistics of output g, inflation π, short yield y(1), and long yield y(40) for counterfactual economies. The last panel considers the full sample, assumes that exogenous shocks are exactly the same as they were realized in the sample, and assumes that only one of the monetary regimes AD (active policy–discretionary shocks), AC (active policy–commitment shocks), PD (passive policy–discretionary shocks), or PC (passive policy–commitment shocks) was realized throughout the full sample. The first panel considers the pre-1982 sample, and, in addition, assumes that the high-volatility regime has prevailed for the output and inflation shocks. The second panel considers the post-1982 sample and assumes that the low-volatility regime has prevailed for the output and inflation shocks.

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<tr>
<td>s1^g</td>
<td>s1^π</td>
<td>s1^y(1)</td>
<td>s1^y(40)</td>
</tr>
<tr>
<td>A C H</td>
<td>–0.51</td>
<td>6.50</td>
<td>8.45</td>
</tr>
<tr>
<td>A D H</td>
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<td>8.27</td>
</tr>
<tr>
<td>P C H</td>
<td>–0.12</td>
<td>7.26</td>
<td>6.83</td>
</tr>
<tr>
<td>P D H</td>
<td>–0.12</td>
<td>7.17</td>
<td>6.68</td>
</tr>
<tr>
<td>A C L</td>
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<td>3.38</td>
</tr>
<tr>
<td>A D L</td>
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<td>4.06</td>
</tr>
<tr>
<td>P C L</td>
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<td>4.81</td>
</tr>
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</tr>
<tr>
<td>A C</td>
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<td>4.97</td>
</tr>
<tr>
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</tr>
<tr>
<td>P C</td>
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<td>4.97</td>
<td>5.54</td>
</tr>
<tr>
<td>P D</td>
<td>0.08</td>
<td>5.00</td>
<td>5.69</td>
</tr>
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</table>

Fig. 7 displays the time series of the simulated counterfactual economies. We observe that in the passive regimes (PD or PC), there is almost no difference between the realized and counterfactual outputs, while counterfactual inflation is higher overall than the realized one. In the active regimes, the counterfactual inflation is lower until 1996. The counterfactual output is slightly higher than the realized one after 1991 in the AC economy, whereas it is sporadically greater or smaller than the realized one in the AD economy. These plots imply that the shocks that occurred were such that the Fed had to face the trade-off discussed above.

To investigate these effects in greater detail, we examine the counterfactual analysis of the time series once again. This time, in addition to fixing all the shocks as they were realized in our dataset, we also fix the realized regimes in volatility of the exogenous shocks (high or low). As before, we commit ourselves to one of the four possible policy–shock combinations: AD, AC, PD, or PC. By fixing one of the policies throughout the sample, but allowing for the realized exogenous shocks, we can evaluate whether the Fed had to face the trade-off against the passive one and whether the trade-off was handled efficiently.

Fig. 8 complements it with the time-series plots. The AD regime, which seemed to be attractive, given the average inflation and output, appears not likely to be implemented as the single prevailing regime because it generates highly volatile yields. In the PD regime, the averages and volatilities are very similar to those obtained from the counterfactual economies. The aforementioned trade-off in managing output and inflation is clear, because the average output is higher in the passive economies while the average inflation is lower in the active economies. Moreover, in the active economies, there is an additional trade-off between the discretionary and commitment regimes, because the discretionary regime leads to lower inflation and higher output at the cost of both variables being more volatile than in the commitment regime.

Evaluating the effect of the various policies on yields informs us about further differences between the regimes. Table 5 reports the averages and standard deviations of the short and long yields and Fig. 8 complements it with the time-series plots. The AD regime, which seemed to be attractive, given the average inflation and output, appears not likely to be implemented as the single prevailing regime because it generates highly volatile yields. In the PD regime, the averages and volatilities are very similar to those obtained from the counterfactual economies. The aforementioned trade-off in managing output and inflation is clear, because the average output is higher in the passive economies while the average inflation is lower in the active economies. Moreover, in the active economies, there is an additional trade-off between the discretionary and commitment regimes, because the discretionary regime leads to lower inflation and higher output at the cost of both variables being more volatile than in the commitment regime.

In the context of the post-1982 moderation, the realized inflation is, on average, lower and less volatile than inflation that results from the implementation of any of the individual regimes. The volatility of realized output is similar to that which occurs in the single-regime counterfactual economies. However, the average
Fig. 7. Counterfactual inflation and output. This figure displays the time series of inflation and output under the assumption that one of the monetary regimes AD (active policy–discretionary shocks), AC (active policy–commitment shocks), PD (passive policy–discretionary shocks), or PC (passive policy–commitment shocks) has prevailed throughout the full sample. Thin lines represent realized output and inflation and thick lines represent counterfactuals.

Realized output is lower than it would have been under the active monetary policy and the realized interest rates are more volatile than the ones in the passive regime. On balance, the Fed appears to have been relatively successful in considering the described trade-offs.

4. Conclusion

We have presented a no-arbitrage term structure model that is complemented with structural identification assumptions in the spirit of the structural VAR literature. The model incorporates the dynamics of changes in monetary policy and the changing volatilities of exogenous shocks that drive the economy.

We demonstrated the presence of at least two types of systematic policy: active and passive. The active regime is characterized by a stronger response to the expected one-quarter inflation. This regime prevailed in the 1970s, throughout the Volcker’s disinflation, in 1991–1995, and in 1995–2004. We also found the presence of two regimes in the volatility of exogenous shocks that were driving the economy: high- and low-volatility regimes. The high-volatility regime is mostly associated with oil shocks and recessions. Finally, we detected two regimes in the volatility of the monetary policy shock, which we called discretion and commitment. These two regimes were interchanged sporadically throughout the sample period.

The yield curve and no-arbitrage restrictions are instrumental in identifying the monetary regimes that are implemented. We found drastically different regimes when the yields were not involved. The simulation study that we performed demonstrates that the yield curve reduces the bias of the estimated monetary policy regimes an order of magnitude. No-arbitrage restrictions help in distinguishing market-based expectations of monetary policy from the objective expectations.

Our assumptions helped us to separate monetary policy changes from changes in the shocks to the private sector; hence, we were able to address the issue of what their relative roles were in the great moderation. We simulated counterfactual economies that maintain realized shocks, but allowed only one set of regimes to prevail throughout the full sample. Low volatility of the private-sector shocks during the post-1982 period makes a clear contribution to moderation. We identified important trade-offs between active and passive monetary policy for managing inflation and output growth, and trade-offs between discretionary
Fig. 8. Counterfactual yields. This figure displays the time series of short \( y(1) \) and long \( y(40) \) yields under the assumption that one of the monetary regimes AD (active policy–discretionary shocks), AC (active policy–commitment shocks), PD (passive policy–discretionary shocks), or PC (passive policy–commitment shocks) has prevailed throughout the full sample. Thin lines represent realized yields and thick lines represent counterfactuals.

and commitment policy shocks for containing the volatility of the state variables and cutting the inflation rate. Overall, our results suggest that monetary policy was important for the moderation, in addition to the fortunate occurrence of the exogenous shocks.

Appendix. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.jeconom.2013.01.002.

References


