The Aggregate Demand Effects of Short- and Long-Term Interest Rates*

Michael T. Kiley
Federal Reserve Board

I develop empirical models of the U.S. economy that distinguish between the aggregate demand effects of short- and long-term interest rates—one with clear "microfoundations" and one more loosely motivated. These models are estimated using government and private long-term bond yields. Estimation results suggest that both short- and long-term interest rates influence aggregate spending. The results indicate that the short-term interest rate has a larger influence on economic activity, through its impact on the entire term structure, than term and risk premiums (for equal-sized movements in long-term interest rates). Potential policy implications are discussed.

JEL Codes: E43, E44, E50.

1. Introduction

The dominant modeling paradigm in macroeconomic models used for monetary policy analysis within the academic community ascribes a central role in aggregate demand determination to the expected path of short-term interest rates, with essentially no direct role for long-term interest rates (e.g., Woodford 2003). Dynamic stochastic general equilibrium (DSGE) models employed by many central banks around the world build on this structure and also often fail to distinguish between expected short-term interest rates and long-term interest rates (e.g., the discussion in Boivin, Kiley, and Mishkin

*This research benefited from comments from colleagues in the Federal Reserve System. The views expressed herein are those of the author and should not be attributed to the Board of Governors of the Federal Reserve System or other members of its staff. Author contact: Office of Financial Stability Policy and Research and Division of Research and Statistics, Federal Reserve Board, Washington, DC 20551. Tel.: (202) 452-2448; Fax: (202) 452-5296; E-mail: mkiley@frb.gov.

2010). In contrast, older large-scale macroeconomic models, such as the Federal Reserve's FRB/US model (Reifschneider, Tetlow, and Williams 1999) and models used in the private sector (e.g., Macroeconomic Advisers 2006 and Moody's Economy.com 2006), assume that long-term interest rates, reflecting both expected short-term interest rates and term/risk premiums (e.g., deviations from the expectations hypothesis), directly affect overall financial conditions and aggregate demand. Because of this assumption, analyses using such models suggest that movements in long-term interest rates induced by shifts in the expected path of short-term interest rates or by changes in term/risk premiums affect real economic activity in much the same way. Indeed, this rough correspondence influences the estimates from such research of the effects on economic activity from policy actions designed to lower term premiums (e.g., Chung et al. 2011 and Fuhrer and Olivei 2011) or the policy prescriptions offered by such analyses (e.g., Gagnon 2011).

A long literature begins with the presumption that short- and long-term assets are imperfect substitutes (e.g., Tobin 1961, 1963; Modigliani and Sutch 1966, 1967; and Vayanos and Vila 2009). Such approaches, suitably modified to include the possibility that imperfect substitutability of financial assets influences the spending of some agents, allow for potentially important roles for both short- and long-term interest rates in spending decisions.

Moreover, in such a framework, the short-term interest rate may have a larger influence on economic activity, through its impact on the entire term structure, than term and risk premiums (for equal-sized movements in long-term interest rates). Informally, such a larger effect is likely to arise because some agents may finance spending by borrowing short (and rolling over such borrowing), implying a role of expected short-term interest rates, whereas other agents may finance spending by borrowing long, implying a link between long-term rates (inclusive of both expected short rates and term/risk premia) and spending; as spending is influenced by expected short rates under both strategies, whereas term/risk premia only affect spending for those agents financing long term, expected short rates are likely a more powerful determinant of aggregate spending than term/risk premia, for equal-sized movements in long-term interest rates. The models developed herein formalize this intuition.

Specifically, models are presented and used to gauge the relative importance of short- and long-term interest rates, or the relative importance of the sequence of expected short-term interest rates and other components (term/risk premiums) of long-term yields, in aggregate demand determination. One model includes optimizing behavior, allows for the possibility that some agents cannot borrow/lend using both short- and long-term securities, and includes frictions that generate deviations of long-term interest rates from the expectations hypothesis; this model is based on Andres, Lopez-Salido, and Nelson (2004)—a framework also used in a larger dynamic stochastic general equilibrium model by Chen, Curdia, and Ferrero (2011). The second model is more loosely connected to a specific set of assumptions regarding optimizing behavior: In this alternative model, aggregate demand is assumed to be determined by the expected path of short-term interest rates and by term/risk premiums—with possibly different sensitivities of aggregate spending to each of these determinants. In broad terms, this approach builds on that of Fuhrer and Moore (1995) and Fuhrer and Rudebusch (2004), with the main addition to their analyses being the inclusion of possible roles for term/risk premiums (which are assumed to have no effect on economic activity and inflation in these earlier models). The empirical analysis will demonstrate that results are robust across the optimization-based and alternative models.

The models are estimated using data for the United States on real GDP, inflation and expected inflation, the short-term interest (federal funds) rate, and long-term interest rates (i.e., yields on Treasury securities or private (corporate) bonds). Each model fits the data similarly along many dimensions. In addition, the estimation results clearly suggest that both short- and long-term interest rates affect spending; the role of short-term interest rates (current and expected) in aggregate demand determination is larger than that of long-term rates, implying that shifts in term/risk premiums have smaller effects on spending than shifts in short-term interest rates for equal-sized movements in long-term interest rates. These results have a similar flavor to those of Andres, Lopez-Salido, and Nelson (2004) and Chen, Curdia, and Ferrero (2011) but move beyond their analysis in several ways. First, these previous analyses focused on Treasury yields, and our analysis finds some differences across results, most especially in a restricted optimization-based framework similar to Andres, Lopez-Salido, and Nelson (2004) or Chen, Curdia, and Ferrero (2011) when considering, alternatively, Treasury and private bond yields. Second, the models considered allow comparison of models strictly derived from optimization-based behavior with a model designed to match the data well, thereby illustrating robustness (in contrast to the more limited explorations of Andres, Lopez-Salido, and Nelson 2004 and Chen, Curdia, and Ferrero 2011). Finally, our presentation focuses on the impact on output of alternative paths for long-term interest rates associated with movements in short-term interest rates or term/risk premiums, thereby addressing policy issues confronted in Chung et al. (2011), Fuhrer and Olivei (2011), and Gagnon (2011).

Before turning to the analysis, two other strands of literature are relevant when thinking about the approach herein. First, purely reduced-form empirical studies have examined the link between activity, the expectations component of long rates, and the term premium component of long rates (Hamilton and Kim 2002, Wright 2006, and Rudebusch, Sack, and Swanson 2007). Such reduced-form correlations obviously cannot address the strength of the negative relationship between spending and interest rates envisaged in IS-curve relationships. The investigation herein, by focusing on specifications suggested by economic theory, is able to identify plausible estimates of the negative relationship between interest rates and economic activity along the lines suggested by textbook analyses.

In addition, a large number of recent studies have examined the degree to which quantitative easing may affect term premiums (e.g., D'Amico and King 2010, D'Amico et al. 2011, Gagnon 2011, Gagnon et al. 2011, Hamilton and Wu 2011, Krishnamurthy and Vissing-Jorgensen 2011, and Swanson 2011). The range of results across these studies suggests considerable uncertainty regarding the effects of quantitative easing on asset prices. In this study, the links between long-term interest rates and real activity are examined using data that pre-dates the recent quantitative easing policies that have motivated studies examining the impact of quantitative easing on term premiums.[1]

Chen, Curdia, and Ferrero (2011) independently explored the separate roles of short- and long-term interest rates concurrently

[1]A third literature is also relevant—namely, the large literature in finance thinking about the term structure and the effect of macroeconomic variables on the term structure (Gurkaynak and Wright 2012). Much of this literature ignores the effect of the term structure on economic activity and inflation, although the integration of macroeconomics and finance is a growing research area (Rudebusch 2010).

with early versions of this analysis. Their work differs along many dimensions. Chen, Curdia, and Ferrero (2011) consider a large DSGE model like those discussed in Boivin, Kiley, and Mishkin (2010), whereas the focus herein is on a smaller model. (It is unclear whether a larger or smaller model is more robust to potential misspecification.) Chen, Curdia, and Ferrero (2011) assume that Treasury yields accurately measure the role of long-term assets/liabilities in the spending decisions of private agents, whereas we consider the role of Treasury and private bond yields. Chen, Curdia, and Ferrero (2011) estimate their model through recent data, including the zero lower bound period, whereas the analysis herein stops before that period in part because it is likely that the binding zero lower bound on nominal interest rates implies that the linear rational expectations structure of the model, which is important in the full system estimation approach used herein and in Chen, Curdia, and Ferrero (2011), may be problematic. Finally, Chen, Curdia, and Ferrero use Bayesian methods, whereas we use maximum likelihood. As we will discuss, the Bayesian approach attributes a larger role to Treasury yields in aggregate demand determination than does maximum likelihood because of the role of prior assumptions. Despite all of these differences, one key conclusion is very similar herein and in Chen, Curdia, and Ferrero (2011): Short-term interest rates have more powerful effects on aggregate demand than long-term interest rates in both studies.

The next section presents two specifications of aggregate demand determination, both of which allow for independent influences of expected short-term interest rates and long-term interest rates on aggregate demand. The third section presents estimation results for both models and explores the plausibility of the empirical estimates. The fourth section considers the implications of the estimation results for the effects of shifts in short-term interest rates and long-term interest rates on economic activity, providing a comparison with other estimates. The final section concludes.

2. The Models

In order to capture the potential importance of financial factors other than the expected path of short-term interest rates, (at least) two features are important. First, as recognized long ago (e.g., Tobin

1961, 1963), financial assets, such as short- and long-term bonds, must be imperfect substitutes in financial portfolios: Such frictions between assets (and/or liabilities)—stemming, for example, from differences in preferences over alternative assets or market structures that result in segmentation—imply that the prices of assets reflect factors other than the expected path of short-term interest rates (and payouts at each date). Second, as emphasized in Andres, Lopez-Salido, and Nelson (2004) (among others), some fraction of households or firms must be restricted from trading in the full set of available financial assets, so that the differences in asset prices associated with imperfect substitutability in portfolio choice influence spending decisions for some agents.

The next sub-section reviews the model of aggregate demand (or more specifically an IS-curve equation) presented in Andres, Lopez-Salido, and Nelson (2004) to capture these features. A second specification of the "IS curve" relaxes the tight theoretical restrictions on dynamics imposed by the optimization-based model while preserving its intuitive aspects. Each specification of aggregate demand (and portfolio choices) is then combined with specifications for monetary policy behavior and inflation dynamics to deliver small structural models of macroeconomic dynamics.

2.1 Optimization-Based IS Curve

We assume that the economy consists of continuums of two types of agents, similar to Andres, Lopez-Salido, and Nelson (2004).

The first type, a fraction α of the population called *unconstrained* agents, can trade in any financial asset, including short- and long-term nominal bonds, subject to a (time-varying, exogenous) transaction cost on long-term bonds. This transaction cost will create deviations of long-term interest rates from those implied by the expectations hypothesis. The second type of agent, a fraction $1 - \alpha$ of the population called *constrained* agents, has limited financial options: They can trade in long-term nominal bonds but have access to no other financial assets.

A brief motivation for these assumptions is in order. Unconstrained agents trading long-term bonds face a transaction cost Ω (a "term" premium) that is not incurred when trading short-term bonds. This exogenous factor should be interpreted as reflecting variations in asset prices due to shifts in the liquidity or risk characteristics associated with these assets. In order for the yield on long-term bonds, inclusive of the "term/risk" premium, to have real effects on spending, it is necessary that unconstrained agents face the transaction cost, while constrained agents do not: Absent this asymmetry, the yield on long-term bonds available to constrained agents would carry the same information as the sequence of expected short-term rates (plus transaction costs) that determine unconstrained agents' willingness to hold the long-term bond, which would thereby (indirectly) make unconstrained agents' spending depend on expected short-term interest rates without the effect of the "term/risk" premium/transaction cost, as emphasized in Andres, Lopez-Salido, and Nelson (2004). Indeed, the asymmetry in costs is exactly what allows this simple model to capture the imperfect substitutability of financial assets (as suggested by Tobin 1961) and the impact of this imperfect substitutability on aggregate demand determination. Andres, Lopez-Salido, and Nelson (2004) discuss these conditions in detail.

Turning to equations, the i-th *unconstrained* (denoted by superscript u) agent faces a budget constraint that includes short-term bonds and a set of long-term perpetuities that pay an exponentially decaying coupon d^s ($d < 1$) in period $t+1+s$, as in Woodford (2001) and Chen, Curdia, and Ferrero (2011):

$$
\begin{aligned}
B^u_{t+1}(i) &+ \sum_{s=0}^{\infty} P^s_{D,t} B^{u,s}_{D,t+1}(i)\,(1+\Omega_t) \\
&\quad + \textit{Other Asset Purchases}_t + P_t C^u_t(i) \\
&= R_{t-1} B^u_t(i) + \sum_{s=0}^{\infty} (P^s_{D,t} + d^s) P_{D,t} B^{u,s}_{D,t}(i) + \textit{Other Asset Payoffs}_t \\
&\quad + W_t L^u_t(i) + D^u_t(i) + T^u_t(i). \qquad (1)
\end{aligned}
$$

$B^u_{t+1}(i)$ are one-period bonds purchased in period t that pay $R_t B^u_{t+1}(i)$ in period $t+1$. $B^{u,s}_{D,t+1}(i)$ are perpetuities issued in period $t-s$, purchased by *unconstrained* agents (and hence the superscript u) in period t at price $P^s_{D,t}$, and that are worth $P^s_{D,t+1}$ and pay d^s in period $t+1$. As noted above, Ω_t is the transaction cost (term/risk premium) on long-term bonds facing unconstrained agents. $C^u_t(i)$

is consumption (of unconstrained agents) in period t, and $W_t L_t^u(i)$, $D_t^u(i)$, and $T_t^u(i)$ are unconstrained agent i's wage, dividend, and lump-sum transfer/tax income.

Preferences over consumptions and work hours for unconstrained agents are given by

$$\mathcal{E}_0 \sum_{t=0}^{\infty} (1+\zeta)^{-t} \left(\frac{(C_t^u(i) - hC_{t-1})^{\gamma}}{1-\gamma} + V\left(L_t^u(i)\right) \right), \tag{2}$$

where $(1+\zeta)^{-1}$ is the time discount factor and C_t is average consumption in the economy in period t (i.e., habits are external). As details regarding preferences over labor supply will not enter this analysis, they are not specified (save the assumption that preferences over consumption and labor are additively separable).

The budget constraint and preferences for unconstrained agents imply the following three optimality conditions for bond-holdings and consumption choices:

$$\mathcal{E}_t\left[\Lambda_t^u\right] = \mathcal{E}_t\left[(1+\zeta)^{-1} R_t \Lambda_{t+1}^u\right] \tag{3}$$

$$\mathcal{E}_t\left[P_{D,t}^s \Lambda_t^u\right] = \mathcal{E}_t\left[(1+\zeta)^{-1} \frac{\left(P_{D,t+1}^s + d^s\right)}{1+\Omega_t} \Lambda_{t+1}^u\right] \tag{4}$$

$$\mathcal{E}_t\left[\Lambda_t^u\right] = \mathcal{E}_t \frac{\left(C_t^u(i) - hC_{t-1}\right)^{-\gamma}}{P_t}. \tag{5}$$

It is straightforward to see, on examination of equation (4), that $P_{D,t}^s$ is equal to $dP_{D,t}^{s-1}$ and that the expected one-period return on all perpetuities is equal.

Taking a log-linear approximation to equations (3) and (4) (using the approximation $Ln(1+x) = x$ and lowercase to denote logs) yields the equation for the term structure of bond yields:

$$\mathcal{E}_t\left[-Dp_{D,t}^0\right] = \mathcal{E}_t\left[D \sum_{j=0}^{\infty} (1-D)^j \left(r_{t+j} + \Omega_{t+j}\right)\right], \tag{6}$$

where $1/D \equiv (P_D^0 + d)/d$ is the duration of the perpetuity (approximately, and as in Fuhrer and Moore 1995 and Fuhrer and Rudebusch 2004) and $-Dp_{D,t}^0$ is the yield on the long-term bond (where multiplication by D expresses the yield in one-period units). This equation for long-term yields is standard (e.g., Fuhrer and Moore 1995)—the long-term yield equals the expected sequence of short-term interest rates, weighted by duration, plus a term/risk premium.

Note that the rate on long-term bonds reflects, in addition to the expected path of short-term interest rates, the "term/risk premium" Ω_t. This structure, which captures the intuition of bond pricing underlying many discussions, was the motivation for the structure of transaction costs introduced earlier. More structural examinations of term/risk premiums should be a priority (e.g., see the discussion in Rudebusch 2010 or Gurkaynak and Wright 2012).

For the i-th *constrained* (denoted by superscript c) agent, the budget constraint is given by

$$\sum_{s=0}^{\infty} P^s_{D,t} B^{c,s}_{D,t+1}(i) + P_t C^c_t(i) = \sum_{s=0}^{\infty} (P^s_{D,t} + d^s) P_{D,t} B^{c,s}_{D,t}(i) + W_t L^c_t(i) + D^c_t(i) + T^c_t(i). \quad (7)$$

Note that constrained agents, which only participate in the long-term bond market, do not face the transaction costs Ω_t on long-term bonds; as emphasized by Andres, Lopez-Salido, and Nelson (2004), such an asymmetry in the frictions facing different agents contributes to separate roles for short- and long-term interest rates in aggregate demand determination.

Preferences over consumptions and work hours for unconstrained agents are given by

$$\mathcal{E}_0 \sum_{t=0}^{\infty} (1+\zeta)^{-t} \left(\frac{(C^c_t(i) - hC_{t-1})^{\gamma}}{1-\gamma} + V\left(L^c_t(i)\right) \right). \quad (8)$$

The budget constraint and preferences for constrained agents imply the following two optimality conditions for bond-holdings and consumption choices:

$$\mathcal{E}_t\left[P^s_{D,t}\Lambda^c_t\right] = \mathcal{E}_t\left[(1+\zeta)^{-1}(P^s_{D,t+1} + d^s)\Lambda^c_{t+1}\right] \quad (9)$$

$$\mathcal{E}_t\left[\Lambda^c_t\right] = \mathcal{E}_t \frac{(C^c_t(i) - hC_{t-1})^{-\gamma}}{P_t}. \quad (10)$$

Given these equations, an IS curve linking aggregate consumption expenditure to expected short- and long-term interest rates can be derived. Define (log) aggregate consumption as $c_t = \alpha c_t^u + (1 - \alpha)c_t^c$ and the aggregate (log) marginal utility of consumption as $\lambda_t = \alpha\lambda_t^u + (1 - \alpha)\lambda_t^c$. From (3) and (9), the aggregate Lagrange multiplier satisfies (ignoring constant terms)

$$\lambda_t = \mathcal{E}_t \left[r_t + (1 - \alpha)\,\Omega_t + \lambda_{t+1}\right] \tag{11}$$

$$\lambda_t = -\gamma^* \left(c_t - hc_{t-1}\right) - p_t, \gamma^* = \frac{\gamma}{1-h}. \tag{12}$$

When bringing this model to the data, these equations are used as a specification for all of aggregate demand, and consumption (c_t) is replaced by output (y_t) in estimation (as in many applications, e.g., Fuhrer and Rudebusch 2004, and as discussed in the estimation section). In addition, an error term ($\epsilon_{y,t}$) is appended to equation (11),

$$\lambda_t = -\gamma^* \left(y_t - hy_{t-1}\right) - p_t, \tag{13}$$

$$\lambda_t = \mathcal{E}_t \left[r_t + (1 - \alpha)\,\Omega_t + \lambda_{t+1}\right] + \epsilon_{y,t}, \tag{14}$$

where $\epsilon_{y,t}$ is distributed $N(0, \sigma_y^2)$. Equations (13) and (14) form the *optimization-based IS curve.*

Several features of the *optimization-based IS curve* deserve highlighting. First, expected short-term interest rates should be expected to have a larger effect on output than term premiums, according to (14), because expected short-term rates directly affect spending for unconstrained agents, who have access to the short-term bond market, and indirectly affect spending for constrained agents, through the term structure equation (6) and the dependence of constrained agents on the private long-term bond for saving/borrowing. The only case in which the coefficient on the term premium approaches that of expected short-term interest rates is the limiting one in which the share of unconstrained agents α approaches zero. Second (as emphasized by Andres, Lopez-Salido, and Nelson 2004), the assumption that *constrained* agents do not pay the transaction costs on long-term bonds is crucial: This assumption ensures that arbitrage does not make long-term yields redundant for spending decisions; this can be seen by comparing equations (3), (4), and (9) and noting that inclusion of the transaction cost Ω_t in (9) would imply (through (3) and (4)) that short-term rates were sufficient statistics for the spending of all agents.

Finally, some readers may be familiar with the form of the IS curve from Andres, Lopez-Salido, and Nelson (2004), which is presented differently from equation (11). Andres, Lopez-Salido, and Nelson (2004) assume that the central long-term security is a zero-coupon bond of maturity L and derive the following IS curve:

$$\lambda_t = \mathcal{E}_t\left[\alpha\sum_{j=1}^{L} r_{t+j+L} + (1-\alpha)\,Lr_t^L + +\lambda_{t+1+L}\right]$$

$$r_t^L = \frac{1}{L}\left[\sum_{j=1}^{L} r_{t+j+L} + \Omega_t^*\right]. \tag{15}$$

Equation (11) is equivalent to equation (15) for Ω_t^* equal to $\sum_{j=0}^{L-1}\Omega_{t+j}$, as can be seen by iterating (11) forward L periods.

2.2 A Semi-Structural IS Curve

The optimization-based model of the IS curve imposes a fair amount of structure, and various researchers have espoused an approach less tightly linked to a specific model of optimization. For example, such approaches might be justified by a view that a model designed to capture consumption dynamics is insufficient to model output; alternatively, some economists may prefer to see an equation loosely tied to an underlying theory, but with more ad hoc dynamics, in order to consider the robustness of any conclusions to assumptions regarding the dynamic implications of cross-equation restrictions and rational expectations.

For these reasons, a *semi-structural IS curve* is also considered. This approach is largely based on the work of Fuhrer and Moore (1995) and Fuhrer and Rudebusch (2004); the latter reference suggests that relaxation of the restrictions implied by an optimization-based IS curve (albeit one without a role for long-term interest rates) is preferred by the data. Specifically, these authors suggest an IS curve for output (y_t) such as

$$
\begin{aligned}
y_t = {} & (\eta_1 + \eta_2) y_{t-1} - \eta_1 \eta_2 y_{t-2} \\
& - \mathcal{E}_t \left[D \sum_{j=0}^{\infty} (1-D)^j \left[a_r \left(r_{t+j} - \Delta p_{t+1+j} \right) \right] \right] + \epsilon_{y,t}.
\end{aligned} \tag{16}
$$

Our semi-structural IS curve (equation (17)) adds a term for the term/risk premium:

$$
\begin{aligned}
y_t = {} & (\eta_1 + \eta_2) y_{t-1} - \eta_1 \eta_2 y_{t-2} \\
& - \mathcal{E}_t \left[D \sum_{j=0}^{\infty} (1-D)^j \left[a_r \left(r_{t+j} - \Delta p_{t+1+j} \right) + a_\Omega \Omega_{t+j} \right] \right] + \epsilon_{y,t}.
\end{aligned} \tag{17}
$$

This specification is an obvious generalization of (16) that includes a role for components of long-term interest rates other than expected short rates as in the optimization-based IS curve (14). This specification can be used to assess the robustness of conclusions drawn from the optimization-based specification.

2.3 Closing the Models

Given a specification for the IS curve, the macroeconomic model is closed through specifications of the exogenous processes for the term premium, an equation for the inflation process, and a set of equations governing monetary policy actions (and hence the course of the short-term interest rate).

With regard to the term premium, the models assume an exogenous autoregressive process (with one lag),

$$
\Omega_t = \rho_\Omega \Omega_{t-1} + \epsilon_{\Omega,t}, \tag{18}
$$

where $\epsilon_{\Omega,t}$ is distributed $N(0, \sigma_\Omega^2)$.

Inflation dynamics are governed by a "New Keynesian Phillips curve," with a role for the lag and lead of inflation,

$$
\Delta p_t = (1-s)\Delta p_{t-1} + s\mathcal{E}_t \Delta p_{t+1} + \psi y_t + \epsilon_{\Delta p,t}, \tag{19}
$$

where $\epsilon_{\Delta p,t}$ is distributed $N(0, \sigma^2_{\Delta p})$. This Phillips curve is a standard form in simple macroeconomic models. However, it should be emphasized that "microfoundations" for such a specification require a number of assumptions to deliver a form in which output enters the Phillips curve (as a measure proportional to marginal cost), and the coefficients on the lead and lag have been assumed to sum to 1, rather than the agents' discount factor; these assumptions are innocuous for this analysis. Finally, it will be assumed below that the inflation target of the monetary authority is stochastic and contains a unit root. As emphasized in Cogley and Sbordone (2008), the presence of a unit root in the inflation target implies that additional assumptions (for example, a specific form of indexation of price setters who are not reoptimizing their price in the current period in the typical Calvo motivation for the New Keynesian Phillips curve) is necessary to deliver the "standard" form assumed above. (Cogley and Sbordone 2008 show that, absent such additional assumptions, additional terms, including the time-varying inflation target, enter the Phillips curve.) Note that under this form of the Phillips curve, an upward shift in the inflation target leads to higher inflation through easier monetary policy (e.g., lower nominal short-term interest rates, ceteris paribus), which boosts output, thereby generating inflationary pressure.

The analysis will use data for ten-year inflation expectations ($\Delta p_{L,t}$), whose equation is

$$\Delta p_{L,t} = \mathcal{E}_t \sum_{j=1}^{40} \left[\Delta p_{t+j-1}\right]. \tag{20}$$

Note that this equation is simply an observation equation that allows the estimation strategy to take into account the information in ten-year inflation expectations for the (unobserved-by-the-econometrician) structural shocks, most notably (but not solely) the change in inflation target, hitting the economy.

Monetary policy is specified via a standard reaction function for the short-term interest rate (r). For this analysis, the specification of Fuhrer and Moore (1995) is used, with the addition of a persistent shock representing a time-varying (persistent) inflation target ($\Delta p*$).

$$\Delta r_t = \phi_{\Delta r,1}\Delta r_{t-1} + \phi_{\Delta r,2}\Delta r_{t-2} + \phi_{\Delta p}\left(\sum_{k=1}^{4}\Delta p_{t-k} - \Delta p*_t\right) + \phi_y y_t + \phi_{\Delta y}\Delta y_t + \epsilon_{r,t}, \tag{21}$$

$$\Delta p*_t = \Delta p*_{t-1} + \epsilon_{\Delta p*,t}, \tag{22}$$

where $\epsilon_{r,t}$ is distributed $N(0,\sigma_r^2)$ and $\epsilon_{\Delta p*,t}$ is distributed $N(0,\sigma_{\Delta p*}^2)$. Note that the time-varying inflation target is a random walk; this highly persistent process will help match the available data on long-term inflation expectations and the term structure of interest rates (as in the time-series analysis of Kozicki and Tinsley 2001).

2.4 Summary of Alternative Model Specifications

To summarize, the model specifications and estimation approach involve the following:

- The *optimization-based IS-curve model* consists of equations (6), (13), (14), (18), (19), (20), (21), and (22).
- The *semi-structural IS-curve model* consists of equations (6), (17), (18), (19), (20), (21), and (22).
- In estimation, the observable variables for each model will be output, inflation, long-term expected inflation, the nominal federal funds rate, and a long-term bond yield (either that on the ten-year Treasury or a composite of Moody's BBB-rated bonds).
- Along with the five observables, there are five exogenous shocks, as outlined above—$\epsilon_{y,t}$, $\epsilon_{\Delta p,t}$, $\epsilon_{\Delta p*,t}$, $\epsilon_{r,t}$, and $\epsilon_{\Omega,t}$.

A few points help clarify some of the estimation results below. The set of equations for both the *optimization-based IS-curve mode*l and the *semi-structural IS-curve model* use the full set of information in the data—output, inflation, long-term expected inflation, the nominal federal funds rate, and a long-term bond yield— and are used to infer the sequence of structural shocks via the Kalman filter (for a given set of parameters). For example, the model-implied long-term interest rate is constructed through the term structure equation, in conjunction with the other equations, by finding the model-consistent expectation for short-term interest rates and the term premium sequence deemed most likely given the parameters. It is also important to remember that, for example, the equation and data for expected inflation over the next ten years are not strictly necessary to estimate the model, but rather to help discriminate (with the other equations and data) the role of very persistent shocks, such as the inflation target, in driving inflation and long-term interest rates.[2] Indeed, the combination of the monetary policy reaction function, the term structure equation, and the behavioral equations ensures that changes in the inflation target pass through, in the long run, to inflation and short- and long-term interest rates (that is, inflation and interest rates share the unit root imparted by the inflation target).

When estimating the model, the set of equations are used to form the model-implied likelihood function (which uses the Kalman filter as above), and the likelihood is maximized over the set of parameters.

3. Estimation Results

The two models are estimated using data for the United States covering the period from the first quarter of 1964 to the fourth quarter of 2007 (before the period when the zero lower bound on nominal interest rates became binding for the nominal federal funds rate). The models are estimated using maximum likelihood.[3]

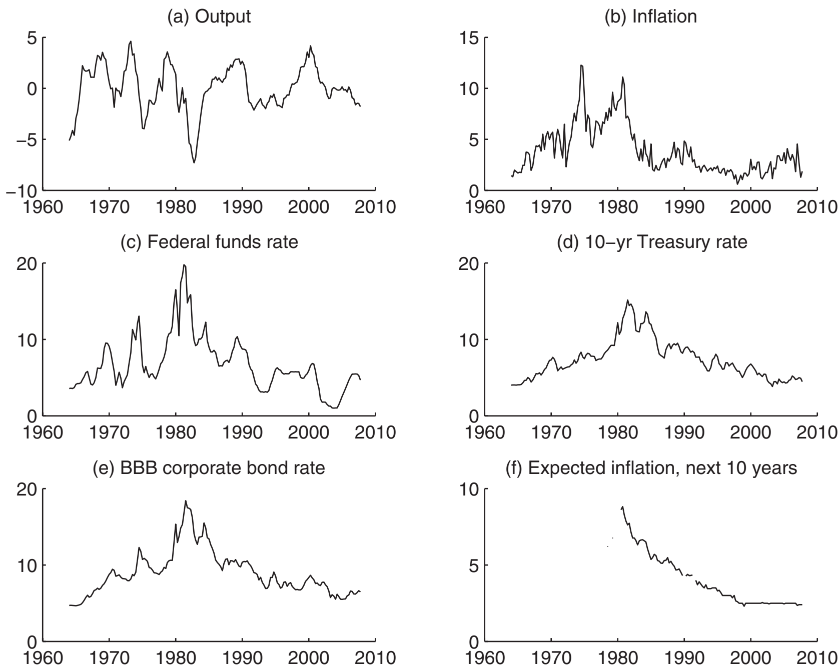
The data used are presented in figure 1.[4] The data for output is given by detrended real GDP, where the trend is removed through a Hodrick-Prescott filter with a large smoothing parameter of 128,000; as shown in the upper left panel, this procedure captures common

[2]As noted below in discussing the data, survey observations for expected inflation over the next ten years only become consistently available in the 1980s, whereas estimation of the model is done using data for other observables from the mid-1960s; the Kalman filter treats missing observations transparently (by imputing the best estimate for the missing data using the model structure and other observable variables), and hence the limited span of data available for ten-year expected inflation poses no hurdles.

[3]Estimation is performed in Dynare 4.2 (Adjemian et al. 2011); programs are available on request.

[4]All data are available from the author on request. As the models describe cyclical dynamics and are not specified at a level of detail designed to pin down the steady state or growth dynamics, all series are demeaned prior to estimation.

Figure 1. Inflation and Interest Rate Data, 1964:Q1 to 2007:Q4



views of cyclical dynamics such as that found in the Congressional Budget Office's measure of the output gap.[5] Inflation is measured by the percent change in the GDP price index; the short-term interest rate is the nominal federal funds rate; the long-term interest rate is either the yield on a ten-year U.S. Treasury security or on a composite long-term corporate bond index, corresponding to bonds rated by Moody's as BBB and with duration of ten years (constructed for use in the Federal Reserve's FRB/US model); and long-term inflation expectations (available sporadically prior to late 1980) are measured by splicing together the data on inflation expected over the next ten years from the Barclays de Zoete survey from over the

[5]Other research has focused on the role of detrending output in estimation of "IS curves" (e.g., Fuhrer and Rudebusch 2004), and this issue is not explored herein.

Table 1. Parameter Estimates (and Standard Errors) for Optimization-Based and Semi-Structural Models: Phillips Curve and Monetary Policy, Treasury Yields

Parameter	Optimization Based	Semi-Structural	Parameter	Optimization Based	Semi-Structural
Phillips Curve					
s	0.58	0.58	ψ	0.005	.001
	(0.014)	(0.014)		(0.007)	(.003)
$\sigma_{\Delta p}$	0.64	0.64			
	(0.039)	(0.039)			
Monetary Policy					
$\phi_{\Delta r,1}$	0.09	0.11	$\phi_{\Delta r,2}$	−0.18	−0.17
	(0.064)	(0.064)		(0.068)	(0.068)
$\phi_{\Delta p}$	0.12	0.13	ϕ_y	0.14	0.10
	(0.043)	(0.044)		(0.041)	(0.035)
$\phi_{\Delta y}$	0.47	0.52	σ_r	1.02	1.03
	(0.100)	(0.101)		(0.056)	(0.057)
$\sigma_{\Delta p*}$	0.20	0.20			
	(0.014)	(0.014)			
Log-Likelihood	−775.4	−771.4			

1980s and early 1990s with the data from the Survey of Professional Forecasters.[6]

Both the optimization-based model and the semi-structural model share coefficients for the Phillips curve and the monetary policy reaction function. Estimates of these parameters for each model, along with the standard errors, are reported in table 1 (corresponding to estimates obtained when long-term interest rates are measured using yields on Treasury securities) and table 2 (corresponding to estimates obtained when long-term interest rates are measured using yields on corporate bonds). In all cases, the common parameters are very similar across the two models. With regard to the Phillips curve, the weight (s) on expected inflation is somewhat larger than that on

[6]The data on long-term inflation expectations was also used by Kozicki and Tinsley (2001).

Table 2. Parameter Estimates (and Standard Errors) for Optimization-Based and Semi-Structural Models: Phillips Curve and Monetary Policy, Corporate Bond Yields

Parameter	Optimization Based	Semi-Structural	Parameter	Optimization Based	Semi-Structural
Phillips Curve					
s	0.58	0.58	ψ	0.002	.000
	(0.013)	(0.013)		(0.004)	(.000)
$\sigma_{\Delta p}$	0.64	0.64			
	(0.038)	(0.038)			
Monetary Policy					
$\phi_{\Delta r,1}$	0.06	0.08	$\phi_{\Delta r,2}$	−0.19	−0.19
	(0.064)	(0.065)		(0.068)	(0.069)
$\phi_{\Delta p}$	0.11	0.13	ϕ_y	0.12	0.11
	(0.043)	(0.046)		(0.037)	(0.038)
$\phi_{\Delta y}$	0.47	0.49	σ_r	1.02	1.03
	(0.099)	(0.104)		(0.056)	(0.057)
$\sigma_{\Delta p*}$	0.20	0.20			
	(0.014)	(0.014)			
Log-Likelihood	−806.7	−802.1			

the lag of inflation. The sensitivity of inflation to the output gap (ψ) is very small, at less than 0.01. Such a small value could be interpreted as indicative of the importance of strategic complementarities in price setting (consistent with other research). Alternatively, this small value may reflect that this parameter is poorly identified: Fuhrer (2010) discusses how estimates of this parameter are sensitive to estimation strategy and reviews related literature. Finally, the small value could reflect misspecification—such as the possibility emphasized by Gali and Gertler (1999) and Sbordone (2002) that the driving variable in the New Keynesian Phillips curve is a measure of marginal cost that is not well proxied by detrended output.

Turning to the coefficients in the monetary policy reaction function, these show important sensitivity of the nominal federal funds rate to inflation, the output gap, and the change in the output gap. As highlighted above, the reaction function is specified in terms of

Table 3. Parameter Estimates (and Standard Errors) for Optimization-Based and Semi-Structural Models: Term/Risk Premiums, Treasury and Corporate Bond Yields

Parameter	Optimization Based	Semi-Structural	Parameter	Optimization Based	Semi-Structural
$1/D$	40 (NA)	40 (NA)			
Treasury Yields					
ρ_Ω	0.97 (0.020)	1.00 (NA)	σ_Ω	0.86 (0.357)	0.63 (0.317)
Corporate Bond Yields					
ρ_Ω	0.97 (0.049)	1.00 (NA)	σ_Ω	1.44 (1.007)	0.88 (0.292)

changes in the nominal interest rate, and hence the value of the coefficient on inflation, near 0.1, is consistent with determinacy. Table 3 reports the coefficients associated with the term/risk premium processes. Long-term bonds are assumed to have a duration of ten years ($1/D = 40$), roughly consistent with the duration of the securities used to measure long-term yields. (Results were insensitive to variations in this assumption.) Term/risk premiums are estimated to be persistent, with the autocorrelation coefficient on the term premium (ρ_Ω) estimated to equal 0.97 in the optimization-based models and estimated to equal 1, the upper-bound consistent with non-explosive dynamics, in the semi-structural specifications. Note that these results are not surprising given the substantial drift in long-term yields apparent in the data (figure 1); results were not sensitive to restricting the upper bound on the persistence of the term/risk premium process to values below, but near, 1. A comparison of the estimated term premium process with that of another model will be presented below, highlighting how highly persistent term premiums are a feature common in the literature.

Table 4 reports the coefficients associated with the optimization-based and semi-structural IS curves. With regard to the optimization-based IS curve, aggregate demand is persistent, as

Table 4. Parameter Estimates (and Standard Errors) for IS Curves: Treasury and Corporate Bond Yields

Parameter	Optimization-Based Treasury Yields	Corporate Bond Yields	Semi-Structural Treasury Yields	Corporate Bond Yields
h	0.94 (0.033)	0.91 (0.031)	NA	NA
γ^*	24.0 (7.76)	39.5 (13.4)	NA	NA
a	1.08 (0.300)	0.56 (0.273)	NA	NA
η_1	NA	NA	0.85 (0.055)	0.81 (0.063)
η_2	NA	NA	0.32 (0.096)	0.35 (0.110)
a_r	NA	NA	1.30 (0.393)	0.95 (0.287)
a_Ω	NA	NA	0.58 (0.489)	0.58 (0.216)
σ_y	20.4 (6.25)	31.5 (10.5)	0.79 (0.044)	0.77 (0.043)
P-value, Short-Rate Impact = Long-Rate Impact	0.000	0.056	0.006	0.081

Notes: The p-value reported at the bottom of the table assumes the null hypothesis that the coefficients on long-term and expected short-term interest rates are equal, with an alternative hypothesis that the coefficients are not equal. P-values are from likelihood-ratio tests comparing the restricted and unrestricted models.

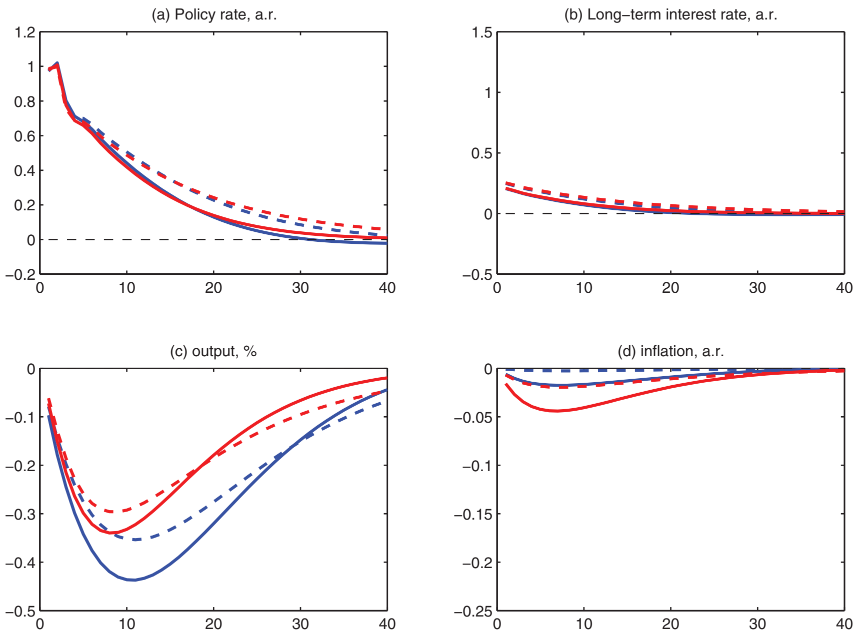
indicated by the habit persistence parameter h estimated to exceed 0.9. The adjusted coefficient of relative risk aversion (γ^*) (whose inverse determines interest sensitivity) is reasonably high, indicating limited short-run interest sensitivity. Most important for the questions considered herein, in economic terms, is the share of aggregate demand linked to long-term interest rates: This share $(1 - \alpha)$, at about 0.4 using corporate bond yields or, more dramatically, at less than, but insignificantly different from, 0 using Treasury yields, suggests a limited role for components of long-term interest rates other than expected short-term interest rates. The p-value for the null hypothesis of equality of the effects of short- and long-term interest rates is near the 5 percent level or smaller in the optimization-based model using either Treasury or private yields, indicating fairly strong evidence against this null. Importantly, these differences are sizable in economic terms (in addition to statistical terms), an issue that will be explored in more detail in the next section.

With regard to the coefficients associated with the semi-structural IS curve, aggregate demand is persistent (with both autoregressive roots positive and the larger autoregressive root (η_1) above 0.8). Expected short-term interest rates exert a sizable effect on output (a_r equal a value near or in excess of 1). Term/risk premiums have a smaller effect on output (a_Ω equal to 0.6). As in the optimization-based model, these results suggest that there are economically important differences between the effect of expected short-term interest rates on output and those of term premiums on output, an issue explored in the next section. The likelihood-ratio tests indicate that the data rejects the null hypothesis that short- and long-term interest rates have the same effect on output at better than a 10 percent level when either Treasury yields or corporate bond yields are used in estimation.[7]

Before turning to the differences in the effects of short- and long-term interest rates in more detail, several properties of the estimated models are presented. First, the (log) likelihoods (reported in the last column of tables 1 and 2) favor somewhat the semi-structural models (even if one were to adjust for the number of parameters

[7]The p-values reported in the table are computed using likelihood-ratio tests comparing the restricted and unrestricted models. Note that these p-values suggest fairly strong evidence against the restriction that the coefficients on expected short-term interest rates and long-term interest rates are equal—evidence that appears stronger than might be inferred by looking at the standard errors in the table for the semi-structural specifications. This occurs for two reasons: First, the standard errors around the parameters in the table do not account for the covariance term between the two relevant coefficients in the semi-structural specification; second, the inverse of the hessian appears to give an incomplete sense of significance—that is, it may be a poor approximation to the variance-covariance matrix. The latter factor is the more important one, and is perhaps not surprising in the case of the semi-structural models, as the estimated parameter for the autoregressive root of the term premium process reaches its upper bound of 1 in these specifications. Related literature suggests that approaches like the likelihood-ratio test may be preferable under these conditions (e.g., Guerron-Quintana, Inoue, and Kilian 2009).

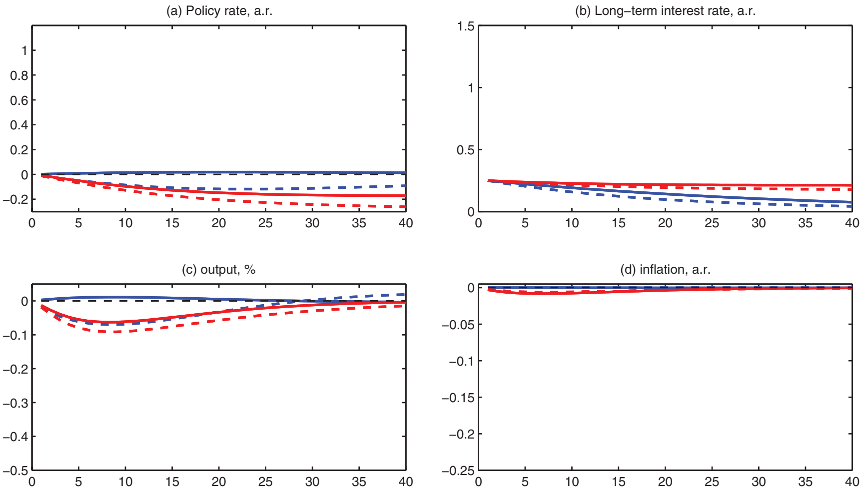
Figure 2. Impulse Response to Monetary Policy Shock (Blue—Optimization Based; Red—Semi-Structural; Solid—Treasury Yields; Dashed—Corporate Bond Yields)



Note: See the online version of the journal at www.ijcb.org for the colored lines in this figure.

via an information criterion; this finding is similar to that of Fuhrer and Rudebusch 2004, who only consider the effect of expected short-term interest rates on output). Four other aspects of the models are noteworthy. First, both models show plausible and similar responses of real activity and inflation to a transitory increase in the federal funds rate associated with a shock to the reaction function (ϵ_r), as illustrated in figure 2: Following an increase in the nominal federal funds rate of 100 basis points (at an annual rate), long-term yields rise about 25 basis points and output falls about 0.3–0.4 percent below baseline about one and a half years following the shock, with inflation declining only marginally. The responses are very similar under both IS-curve specifications and for estimates based on data using Treasury or corporate bond yields, highlighting the similar fit

Figure 3. Impulse Response to Term/Risk Premium Shock (Blue—Optimization Based; Red—Semi-Structural; Solid—Treasury Yields; Dashed—Corporate Bond Yields)



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of each model. These results fall well within the range reported in the literature (as documented in the survey of Boivin, Kiley, and Mishkin 2010).

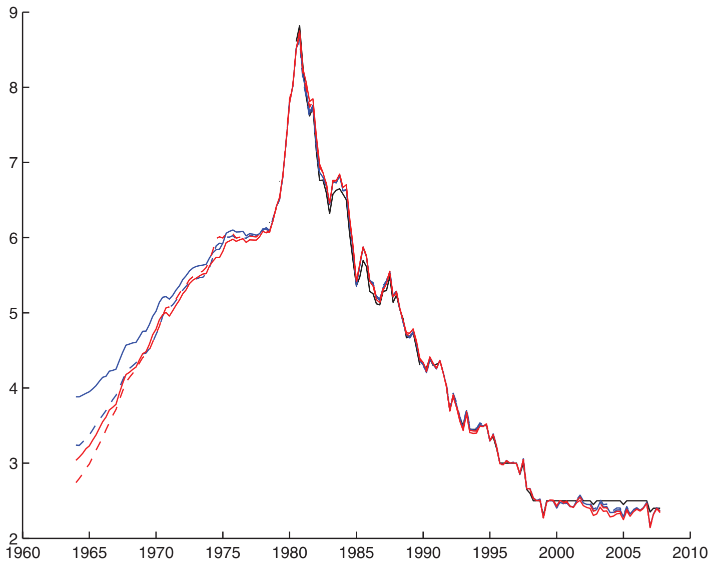
These results can be compared with impulse responses following a shock to the term/risk premium, presented in figure 3. The term premium shock is chosen to deliver a 25-basis-point increase in the long-term yield, the same change as that implied by the monetary policy shock reported in figure 2. Despite the similar movement in the long-term interest rate, output declines only 0.1 percent (or less)—notably below the 0.3–0.4 percent decline from the monetary policy shock that lowers long-term interest rates by 25 basis points and consistent with the relatively small role for long-term interest rates in aggregate demand determination highlighted in our discussion of the estimated parameters. Note that this result is robust across models and measures of long-term yields. Two other aspects of these impulse responses are notable. First, the contractionary effect of the term premium shock (in three of the specifications, albeit not in the optimization-based model estimated using Treasury yields) results in a lower path for the federal funds rate—implying that the impulse responses cannot be interpreted as a guide to the pure effect of long-term interest rates relative to short-term interest rates; section 4 will consider experiments highlighting the pure effects of the different roles for short- and long-term interest rates in the IS curves. Second, the term premium processes in the semi-structural specifications have a unit root, and hence the endogenous decline in the short-term interest rate (via the monetary policy reaction function) is important for returning output to steady state.[8]

Another important feature of the models is that they ascribe a primary role to persistent shifts in the desired rate of inflation ($\Delta p*$) in the determination of long-run inflation expectations and long-term interest rates (a finding related to that of Kozicki and Tinsley 2001). Figure 4 reports the survey measure of expected inflation over the next ten years along with the estimated level of $\Delta p*$; the series move closely together, as should be expected, in both models and using either measure of yields on long-term bonds. Note that, as emphasized above, this close correspondence between the data on expected inflation over the next ten years and the inflation target does not occur because the survey measure is assumed to be very similar to the inflation target, but rather arises because the ten-year horizon is long, and the transitory fluctuations in inflation are fairly small at the estimated parameters.

Each model (estimated using Treasury yields) also provides an estimate of the term premium on the ten-year Treasury bond. The estimated term premiums behave very similarly to those from standard term structure models used in the finance literature, such as that of Kim and Wright (2005). Figure 5 reports the term premium from each model of the IS curve and the term premium on a

[8]Note that the short-term interest rate declines permanently in response to a permanent increase in the term premium, thereby implying fluctuations in the long-run equilibrium short-term interest rate as defined by Laubach and Williams (2003); note that the degree to which short-run interest rates move depends on the relative importance of short- and long-term interest rates in the IS curve. While Laubach and Williams (2003) do not consider explicitly persistent changes in financial factors such as term/risk premiums as a contributor to variation in the long-run equilibrium short-term interest rate, this is an interesting area for research.

Figure 4. Long-Run Inflation Expectations (Black) and Target Inflation (Blue—Optimization Based; Red—Semi-Structural; Solid—Treasury Yields; Dashed—Corporate Bond Yields)



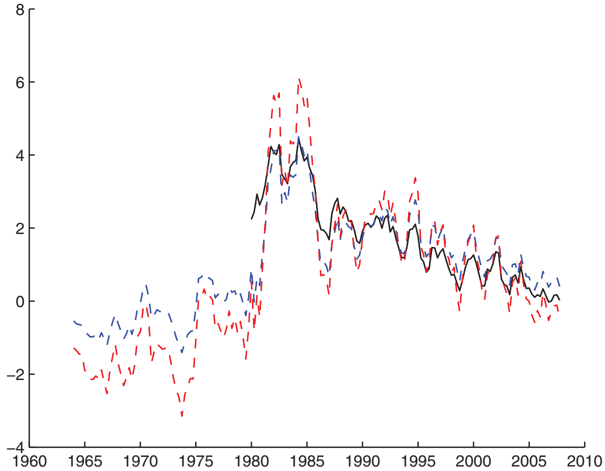
Note: See the online version of the journal at www.ijcb.org for the colored lines in this figures.

ten-year zero-coupon Treasury security from the model of Kim and Wright (2005): The series move closely together, with a simple correlation exceeding 0.85 since 1980.[9] The similarity across the series of term premiums derived from the models herein and that in other research provides some comfort that the estimation results regarding the effects of term premiums on real activity may not be solely the result of idiosyncratic modeling choices.

In particular, the highly persistent nature of term premiums is a feature of the literature in general and not a result specific to the models analyzed herein. For example, the first-order autocorrelation

[9]Kim and Wright (2005) only provide estimates of the term premium back to 1990; the series plotted uses their specification extended back to 1980 and is constructed by staff at the Federal Reserve Board.

Figure 5. Estimates of the Term Premium on the Ten-Year Treasury Security (Black—Kim-Wright; Blue—Optimization Based; Red—Semi-Structural)



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of the Kim-Wright measure equals 0.97 (in the quarterly data shown in the graph), not dissimilar to the autoregressive coefficient in the optimization-based models.

4. The Effects of Short- and Long-Term Interest Rates

The estimated parameters highlight a larger role for short-term interest rates than for term premiums in the determination of aggregate demand, as can be seen by the estimated value of α for the model with the optimization-based IS curve and the values of a_r and a_Ω for the semi-structural IS curve. However, it is not entirely straightforward to see the implications of alternative paths of long-term interest rates, driven by either short-term rates or term premiums, from these coefficients, as the dynamics are complex and depend on expectations (most especially in the case of the optimization-based IS curve). Moreover, the impulse responses to a term premium shock, shown in the previous section, include the effect of the endogenous response of short-term interest rates.

To illustrate the different effects of short- and long-term interest rates operating through the IS curve, the impact on output and inflation of paths is shown for two cases that lower long-term interest rates by 100 basis points in the initial year: In the first, the shift in long-term interest rates is caused by a gradual lowering (and then return to baseline at an exponential decay rate of 0.9) of the federal funds rate by 400 basis points; in the second, an identical path of the long-term interest rate is caused by a lower term premium, holding short-term interest rates constant. In both cases, the simulations assume perfect foresight on the part of agents regarding the paths of interest rates.

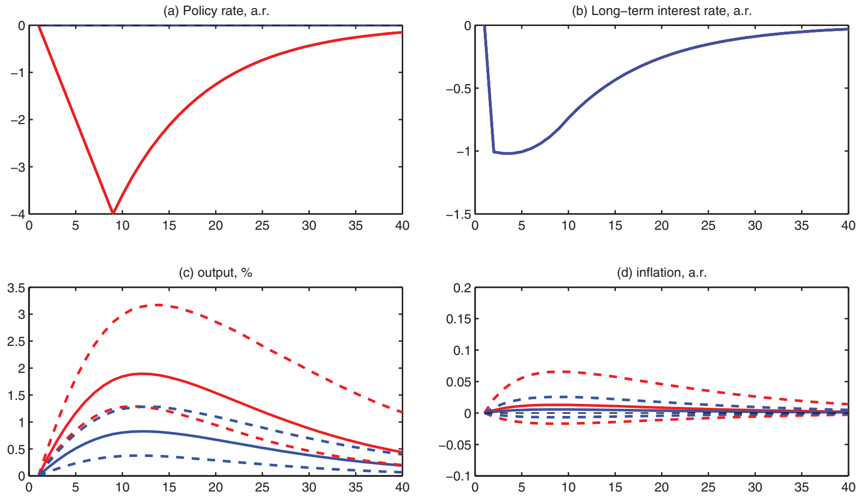
In considering these simulations, it is important to remember that the assumed movements in short-term interest rates, term/risk premiums, and long-term interest rates are chosen to imply the same path of long-term interest rates in each simulation. This requires that monetary policy and the term premium evolve in a manner different from that which is historically typical (given the estimated policy reaction function and process for the term/risk premium). These experiments are valid under the structural interpretation of the model specifications, where changes in the policy reaction function or term premium process do not affect the coefficients in the IS and Phillips curves. Moreover, these experiments provide clear pedagogical insight—namely, they illustrate the dynamic differences between the output (and inflation) movements induced by changes in short-term interest rates or long-term interest rates conditional on the same path for long-term interest rates.

4.1 Results for Estimation Results Using Corporate Bond Yields

In the first set of simulations, results are presented using the parameters estimated for the optimization-based model when long-term yields are measured by corporate bonds. (The working-paper version contains results using the semi-structural model, which are very similar.[10]) I use the parameters estimated with the data on private yields

[10] The working-paper version is available at http://www.federalreserve.gov/pubs/feds/2012/201254/201254abs.html.

Figure 6. Differential Impact of Expected Short-Term Interest Rates and Term Premiums, Optimization-Based Model (Blue—Term Premiums; Red—Short-Term Policy Rate; Solid—ML Parameters; Dashed—68 Percent Confidence Interval)



Note: See the online version of the journal at www.ijcb.org for the colored lines in this figure.

because this case shows a larger role for long-term interest rates (and hence could be viewed as an upper-bound estimate of the relative importance of term/risk premiums). That said, other research (e.g., Chen, Curdia, and Ferrero 2011) uses Treasury yields, so the next sub-section considers the results using parameters estimated when long-term interest rates are measured by Treasury yields.

Figure 6 reports the results (see the online version of the journal at www.ijcb.org for the colored lines discussed here and in other figures). The blue lines report the results for the model with the optimization-based IS curve, and the red lines report the results for the model with the semi-structural IS curve. For both models, the solid line reports the results for the shift in short-term interest rates, and the dashed line reports the results for the shift in the term premium. The upper two panels present the paths for short- and long-term interest rates; the long-term interest rate is about 100 basis points lower for approximately two years. When the change in interest rates is induced by a shift in the short-term rate, the effect on output is sizable: Activity increases by 2 percent, with the impact peaks in the third year. The effects are more muted when the shift in long-term interest rates arises because of a decline in the term premium: In this case, activity increases by between 3/4 and 1 percent. These simulations show that a sustained decline in long-term interest rates brought about by a decline in the term premium has about one-half the effect of a similar decline in long-term interest rates brought about through a decline in short-term interest rates.

Note that these results are obtained assuming no response of short-term interest rates following higher activity and inflation—in order to highlight the differential roles of expected short-term interest rates and term/risk premia in the dynamic responses of output and inflation; Chen, Curdia, and Ferrero (2011) emphasize that this case results in much stronger output effects than the case in which short-term interest rates adjust to macroeconomic conditions, and hence should perhaps be viewed as an upper bound. This is apparent from our earlier discussion of impulse responses to a term premium shock (figure 3), which included the endogenous response of the short-term interest rate and showed output responses following a term-premium shock that were one-fourth to one-third as large as responses to a shock to the short-term interest rate (assuming similar-sized movements in the long-term interest rate).

4.2 Results for Estimation Results Using Treasury Yields

Results are now presented using the parameters estimated for the optimization-based model when long-term yields are measured by Treasury yields. These exercises serve two purposes. First, the estimated parameters using Treasury yields show essentially no direct role for long-term interest rates in aggregate demand determination, and hence show results in line with those from the simplest New Keynesian model, where long-term rates play no role (e.g., Woodford 2003); however, in this case the estimation procedure provides confidence intervals around this assessment, which can be usefully examined to think about the information on this issue contained in the data on Treasury yields. Second, these results can be compared with other work that uses Treasury yields such as Chen, Curdia, and Ferrero (2011).

Figure 7. Differential Impact of Expected Short-Term Interest Rates and Term Premiums, Optimization-Based Model (Blue—Term Premiums; Red—Short-Term Policy Rate; Solid—ML Parameters; Dashed—68 Percent Confidence Interval)

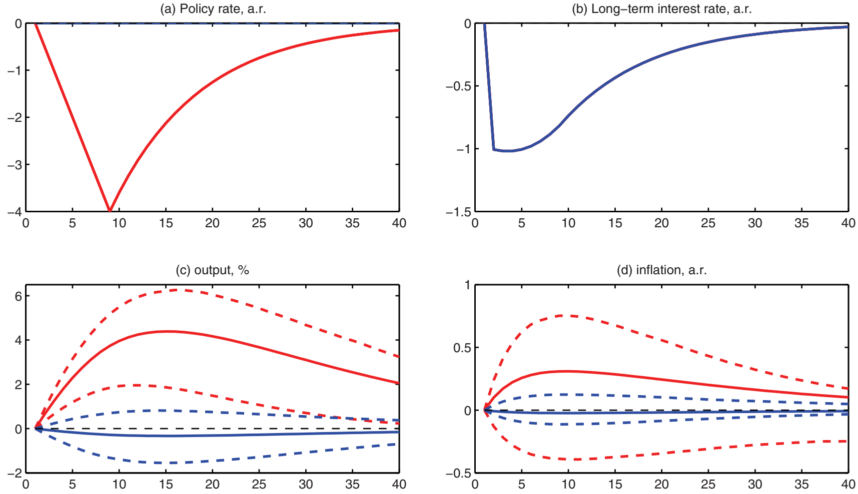


Figure 7 reports the results; as before, the red line reports the results for the shift in short-term interest rates, and the blue line reports the results for the shift in the term premium. The dashed (and appropriately colored) lines report 68 percent confidence intervals. As in the case when data on corporate bond yields were used, the effect on output is sizable when the change in interest rates is induced by a shift in the short-term rate: Activity increases by more than 4 percent, with the impact peaking in the third year. Note that this response of output is larger than that estimated using corporate bond yields (where output increased about 2 percent), consistent with the difference in γ^* associated with Treasury and private yields (reported in table 4). These differences are not out of line with estimates in the literature (e.g., Fuhrer and Olivei 2011 consider a range of impacts from just above 2 percent to 4 percent), and the 68 percent confidence intervals for output in figures 7 and 6 overlap considerably.

As should be expected given that the parameter estimates for the optimization-based model estimated using Treasury yields show no role for long-term interest rates, output is (essentially) unaffected by the decline in long-term interest rates engendered by a decline in term premiums (the blue line). That said, there is considerable uncertainty regarding this assessment: The upper band of the impulse response of output to the shift in the term premium reaches 3/4 percent (the dashed blue line), and the upper bound of the 95 percent confidence interval reaches 2 percent (not shown). Such uncertainty is two sided, and hence the confidence intervals include sizable declines in output as well. However, one interpretation of these results is that the data on Treasury yields strongly suggest that the effects of movements in long-term interest rates induced by changes in term premiums is less than that of such shifts induced by short-term interest rates, but are also relatively uninformative about the impact of shifts in term premiums—and hence consistent with sizable (positive or negative) effects.

4.3 Summary

In broad terms, our results are similar to those in Andres, Lopez-Salido, and Nelson (2004) and Chen, Curdia, and Ferrero (2011). A few points of difference are important, however. First, Chen, Curdia, and Ferrero (2011) only considered Treasury yields; in our results, estimates were somewhat different across cases in which long-term yields were measured by those on Treasury securities and those on corporate bonds, especially within the optimization-based model similar to that of Chen, Curdia, and Ferrero (2011). This is important because Chen, Curdia, and Ferrero (2011) use Bayesian methods in which the priors over the share of agents who are constrained to use long-term assets/liabilities are centered at one-half and are somewhat informative, pushing the posterior mode toward that value. Our results suggest this procedure may be quantitatively important—as our maximum-likelihood approach pushed the role of long-term interest rates in aggregate demand to the edge of the region allowed by Chen, Curdia, and Ferrero (2011) and highlighted the wide confidence intervals associated with estimation results using Treasury yields.

We also considered a set of models that included the optimization-based approach of Andres, Lopez-Salido, and Nelson

(2004) and Chen, Curdia, and Ferrero (2011) as well as more loosely motivated semi-structural specifications with broadly similar results; this suggests that the results are robust to relaxation of the tight restrictions of the optimization-based model used herein, by Andres, Lopez-Salido, and Nelson (2004) and by Chen, Curdia, and Ferrero (2011).

Finally, our presentation, focusing on sustained declines in long-term interest rates associated with either lower short-term interest rates or lower term/risk premiums, ties somewhat more closely to some policy discussions (e.g., Chung et al. 2011 and Gagnon 2011).[11]

5. Conclusion

Both short- and long-term interest rates are key determinants of spending decisions. This analysis has presented two models of aggregate demand determination that distinguish between the effect on spending of expected short-term interest rates and other determinants of long-term interest rates such as term and risk premiums. In contrast to the simple models that dominate the academic literature (e.g., Woodford 2003), long-term interest rates clearly influence aggregate demand beyond the effect of the expected path of short-term interest rates. However, consistent with a model of imperfect substitutability of financial instruments and the associated implications for aggregate demand (as in Tobin 1961, 1963, and Andres, Lopez-Salido, and Nelson 2004), expected short-term interest rates exert a larger effect on aggregate demand than that exerted by term premiums.

Previous discussions of the potential effect of quantitative easing on long-term interest rates and aggregate demand have not drawn sharp distinctions regarding the impact on output of shifts in short-term interest rates or term premiums (e.g., Chung et al. 2011, Fuhrer and Olivei 2011, and Gagnon 2011). The results of this empirical

[11]Despite all of these advantages, the approach of Chen, Curdia, and Ferrero (2011) also has advantages relative to the analysis herein. For example, their Bayesian approach allows a full consideration of the uncertainty regarding estimates and implications. In addition, their use of a complete DSGE model, while potentially subject to misspecification, provides a more complete description of macroeconomic dynamics. Overall, the results herein and in Chen, Curdia, and Ferrero (2011) are complementary.

analysis suggest that it is important to differentiate between the effects on spending of different components of long-term interest rates. The empirical findings herein would suggest that movements in term premiums have smaller effects on real activity than movements in expected short-term interest rates, for equal-sized movements in long-term interest rates.

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