The Excess Sensitivity of Long-Term Interest Rates: Evidence and Implications for Macroeconomic Models*

Refet S. Gürkaynak,

Brian Sack,

and

Eric Swanson

Division of Monetary Affairs
Board of Governors of the Federal Reserve System
Washington, DC 20551

June 23, 2003

* The opinions expressed are those of the authors and do not necessarily reflect the views of the Board of Governors or other members of its staff. We thank Emily Cauble for research assistance and Ken Kuttner, Qiang Dai, Tao Wu, Sharon Kozicki, and seminar participants at the Federal Reserve Board, University of Virginia, and the Stanford-FRBSF Conference on Finance and Macroeconomics for helpful comments and suggestions. The authors can be reached at refet.gurkaynak@frb.gov, brian.sack@frb.gov, eric.swanson@frb.gov.

The Excess Sensitivity of Long-Term Interest Rates:
Evidence and Implications for Macroeconomic Models

Abstract

This paper demonstrates that long-term forward interest rates in the U.S. often react considerably to surprises in macroeconomic data releases and monetary policy announcements. This behavior is in contrast to the prediction of many macroeconomic models, in which the long-run properties of the economy are assumed to be time-invariant and perfectly known by all economic agents: Under those assumptions, the shocks we consider would have only transitory effects on short-term interest rates, and hence would not generate large responses in forward rates. Our empirical findings suggest that private agents adjust their expectations of the long-run inflation rate in response to macroeconomic and monetary policy surprises. We present an alternative model that captures this behavior. Consistent with our hypothesis, forward rates derived from inflation-indexed Treasury debt show little sensitivity to these shocks, indicating that the response of nominal forward rates is mostly driven by inflation compensation. In addition, we find that in the U.K., where the long-run inflation target is known by the private sector, long-term forward rates have not demonstrated excess sensitivity since the Bank of England achieved independence in mid-1997.

1. Introduction

Current macroeconomic models provide appealing, succinct descriptions of business cycle dynamics in the U.S. and other countries, but less is known about the extent to which these models accurately replicate the economy's long-run characteristics. In part, this reflects the fact that economists have far fewer observations about long-run behavior, given the limited sample sizes available. But while less is known about the long-run characteristics of the economy, many macroeconomic models impose very strong assumptions about this behavior—that the long-run levels of inflation and the real interest rate are constant over time and perfectly known by all economic agents. This paper empirically tests those assumptions and proposes alternative ones.

More specifically, we focus on the effects of macroeconomic and monetary policy surprises on the term structure of interest rates. In standard macroeconomic models, short-term interest rates tend to return relatively quickly to a deterministic steady state after a macroeconomic or monetary policy shock, so that these shocks have only transitory effects on the future path of interest rates. As a result, one would expect only a limited response of long-term interest rates to these disturbances. Putting this prediction in terms of forward rates, one would expect virtually no reaction of long-term forward rates to such shocks.

However, the behavior of the U.S. Treasury market appears to contrast significantly with these predictions. In particular, we demonstrate that long-term forward rates have a tendency to move significantly in response to the unexpected components of monetary policy decisions and a number of macroeconomic data releases, which we refer to as *excess sensitivity*.

The paper then turns to potential explanations for this behavior. We find that time-varying term premia are unlikely to be an adequate explanation, given that we observe excess sensitivity of long rates following a variety of shocks that one would expect to have different implications for the term premium. We interpret our findings as instead indicating that an assumption made in these models—that the long-run expectations of economic agents are precise and time-invariant—is violated. In particular, our empirical results are all consistent with a model that we present in which private agents' views of long-run inflation are not strongly anchored.

We bring additional empirical evidence to bear on our hypothesis from two sources. First, we look at real forward interest rates computed from inflation-indexed U.S. Treasury debt. We find that those rates generally do not respond to macroeconomic and monetary policy surprises, which indicates that the excess sensitivity of nominal forward rates derives from their compensation for expected inflation. Second, we investigate whether excess sensitivity is also observed in the U.K., where the long-run inflation target is known by the private sector. We find that long-term forward rates in the U.K. responded significantly to some macroeconomic news prior to mid-1997, but that this responsiveness has largely disappeared since the Bank of England gained independence, perhaps because its explicit long-run inflation target became more credible.

2. Long-run Implications of Macroeconomic Models

Standard macroeconomic models assume that the long-run characteristics of the economy, such as the levels of inflation and the real interest rate, are constant over time and perfectly known by all economic agents. An implication of this assumption is that, after a macroeconomic or monetary policy shock, expectations of short-term nominal interest rates far enough in the future should remain relatively fixed.

This effect is illustrated in Figure 1, which plots impulse response functions for short-term nominal interest rates from two standard macroeconomic models: the "New Keynesian" model (taken from Clarida, Gali, and Gertler (2000) and depicted by the solid lines) and, since the New Keynesian model has often been criticized for its inability to generate appreciable inflation persistence (Estrella and Fuhrer, 2002), a modification of the model that allows for a significant fraction of "backward-looking" or "rule of thumb" agents (dashed lines). These two models can be summarized by the following equations:

$$\pi_t \;=\; \mu\, E_t \pi_{t+1} \;+\; (1-\mu)\, A_\pi(L)\, \pi_t \;+\; \gamma\, y_t \;+\; \varepsilon_t^\pi \qquad (2.1)$$

$$y_t \;=\; \mu\, E_t y_{t+1} \;+\; (1-\mu)\, A_y(L)\, y_t \;-\; \beta\,(i_t - E_t \pi_{t+1}) \;+\; \varepsilon_t^y \qquad (2.2)$$

where π denotes the inflation rate, *y* the output gap, *i* the short-term nominal interest rate, and ε^π and ε^y are i.i.d. shocks.[1] The parameter μ denotes the degree of forward-looking behavior in the model, and the lag polynomials $A_\pi(L)$ and $A_y(L)$ summarize the parameters governing the dynamics of any backward-looking components of the model.

In the analysis that follows, we will consider two variants of the model that differ in their degree of forward-looking behavior. In the first case, we assume that agents are completely forward-looking, or μ=1, as in the standard New Keynesian model. For that model, we take the parameter values for these equations from Clarida, Gali, and Gertler (2001). However, much smaller values of μ (around 0.3) have been estimated and advocated by Fuhrer (1997), Roberts (1998), and Rudebusch (2001) to match the degree of persistence in U.S. data. Thus, we consider a second case in which μ=0.3 due to backward-looking or "rule of thumb" agents, and we take parameter values from Rudebusch (2001).[2]

We close these two models with an interest rate rule of the following form:

$$i_t = (1-c)\big[(1+a)\overline{\pi}_t + b y_t\big] + c\, i_{t-1} + \varepsilon_t^i \qquad (2.3)$$

[1] These variables are all normalized to have steady state values of zero. We consider extending the model to have persistent shocks in section 4, below.

[2] Rudebusch estimates and uses a value of μ=0.29, so we use that value as well. There are also some minor timing differences between equations (2.1)-(2.2) and the specification of Rudebusch's model. To generate the impulse response functions in Figure 1, we use the model exactly as specified in Rudebusch (2001), but these differences in specification have no discernible effect on our results.

where $\overline{\pi}$ denotes the trailing four-quarter moving average of inflation, ε^i is an i.i.d. shock, and a, b, and c are the parameters of the rule.[3] Note that the policy rule is both "backward-looking," in that the interest rate responds to current values of the output gap and inflation rather than their forecasts, and "inertial," in that it includes the lagged federal funds rate. Both of these characteristics tend to add inertia to the short rate, which generally gives these models the best possible chance to explain the term structure evidence we find below. We include an interest rate shock, ε_t^i, for the purpose of generating impulse response functions, below.

The three panels of Figure 1 show the response of the short-term nominal interest rate to a one-percent shock to the inflation equation, the output equation, and the interest rate equation, respectively, under our two baseline models. In all of the panels of the figure, the effects of the macroeconomic and monetary policy shocks on interest rates die out quite quickly, generally within just a few years. After 10 years have passed, short-term interest rates have in all cases essentially returned to their steady-state level. We now turn to how well these predictions are matched by the data.

3. The Excess Sensitivity of Long-term Interest Rates

The previous section demonstrated that, for some common macroeconomic models that assume a constant steady state, the reaction of the short-term interest rate to various macroeconomic shocks tends to die out within a few years. As a result, expectations of short-term interest rates at horizons beyond several years should be well anchored. This section investigates whether this prediction is consistent with the behavior of the term structure of interest rates.

It is perhaps easiest to think of the term structure implications of the models in terms of forward rates rather than yields. A yield represents the return that an investor demands to

[3] We use the values of a, b, and c estimated by Rudebusch (2002) for the period 1987Q4 to 1999Q4: a=.53, b=.93, and c=.73.

lend money today in return for a single payment in the future (in the case of a zero-coupon bond). A forward rate instead represents the rate of return that an investor would demand today to commit to lending money, say, nine years ahead for a payment ten years ahead. The linkage between these concepts is simple: a ten-year zero-coupon security can be thought of as a string of forward rate agreements to lend money for one-year periods today, in one year, in two years, and so on up to nine years. Thus, forward rates are simply a different way of expressing the yield curve. Formally, the continuously-compounded yield on a zero-coupon security with a maturity of *m* years, $y_t(m)$, can be written as an average of *m* one-year forward rates:

$$y_t(m) = \frac{1}{m}\sum_{i=1}^{m} f_t(i,1) \ , \tag{3.1}$$

where $f_t(i,1)$ is the forward rate at time *t* for a one-year period ending *i* years ahead. If we observed zero-coupon market yields at all maturities, those yields could be equivalently expressed by the forward rates that they imply. In practice, however, Treasury notes and bonds have coupon payments and somewhat irregular maturity dates. Thus, we estimate a smoothed zero-coupon yield curve using the method of Svensson (1994) and calculate the forward rates implied from the smoothed curve.[4]

3.1 The Excess Volatility of Forward Rates

The advantage of using forward rates is that they serve as a proxy for expectations of future values of the short-term interest rate, up to a term premium. If the term premium is relatively stable over time, the models from the previous section indicate that long-term forward rates should be well anchored. This is demonstrated in Figure 2, which shows the standard deviation of forward rates at various horizons from simulations of the Rudebusch model, under the assumption that term premia are constant.[5] The predicted

[4]The Svensson zero-coupon curve is estimated through off-the-run Treasury notes and bonds, to avoid on-the-run liquidity premia. Below, we show that our results are robust to computing forward rates directly from Treasury STRIPS data, which require no smoothing assumptions.

[5] The figure plots the standard deviation of the quarter-to-quarter change in the corresponding 1-year forward rate at each horizon. For comparability to the model, we sample our Treasury data at quarterly frequency over our sample period (1990-2002).

volatility term structure is strongly downward-sloping in the horizon of the forward rate.[6] The volatility term structure from the CGG model would decline even more sharply, given the limited dynamics of the interest rate shown in Figure 1.[7]

By contrast, the observed term structure of volatility barely slopes downward at all, and the volatility of forward rates remains considerable even at very long horizons. Thus, there is a considerable discrepancy between the models and the term structure evidence. This finding is related to a well-known puzzle—that long-term interest rates seem surprisingly volatile, which we will refer to as the *excess volatility puzzle*. Indeed, Shiller (1979) first showed that long-term interest rates are substantially more volatile than one would expect given the subsequent realizations of short-term interest rates and a constant risk premium. Our results show the same finding in terms of forward rates, only where expectations of future interest rates are derived from an assumed class of models.[8]

Of course, the greater-than-expected volatility of long-term forward rates in the data could be explained by time-varying term premia on those instruments. Indeed, there is no reason to expect term premia to be constant over time. Once the assumption of a constant risk premium at each maturity is relaxed, one could perfectly replicate the observed term structure of volatility by assuming a random term premium of an appropriate magnitude.

However, we present additional evidence about the volatility of long-term forward rates that cannot be explained by simply adding a time-varying term premium to the model. In particular, we demonstrate that the excess volatility of long-term forward rates in part arises from their systematic responses to surprises in a variety of macroeconomic data

---

[6] Rudebusch calibrates the variances of the disturbances to the model from the observed behavior of inflation and the output gap since 1968. This helps explain why the volatility term structure from the simulated model begins well above the realized volatility, which is calculated since 1990. We assume that there are no monetary policy shocks when computing the model's predictions, but including such shocks has no effect on the qualitative nature of the figure.

[7] We do not show results from simulating the CGG model because they do not report variances for the shocks to their model.

[8] This finding is also consistent with the importance of the "level" factor in explaining yield curve movements in the finance literature (Knez, Litterman, and Scheinkman, 1991).

releases and monetary policy announcements. We refer to this behavior as the *excess sensitivity puzzle.*

In establishing the empirical evidence, our intention is to condition on events that would, under the macroeconomic models described above, be perceived as having transitory implications for the path of short-term interest rates. The remainder of this section focuses only on quantifying the reaction of the yield curve to these shocks. In section 4, we will discuss possible explanations for our findings and the implications of our results for macroeconomic models.

3.2. The Excess Sensitivity of Long-term Interest Rates to Macroeconomic News

We begin our analysis by looking at the response of the term structure to macroeconomic data releases. We have collected data on the released values of 39 different macroeconomic statistics going as far back as 1990. In the regressions below, we estimate the market reaction to the surprise component of these releases.

To measure market expectations for each macroeconomic data release, we use the median market forecast as compiled and published by Money Market Services the Friday before each release. The sample over which the MMS data are available to us varies across the individual releases. The surprise component of each data release is computed as the actual released value less the market expectation. These surprises have zero means, as expected.

In the analysis that follows, we regress daily changes in the one-year forward rate at each horizon on a constant and a list of macroeconomic surprises.[9] This approach has the advantage of capturing the effects of all data releases in a single regression, which will properly parse out the response of the forward rate when there are multiple releases on a given day. We divide each surprise series by its standard error so that the regression coefficients are comparable across series and are easily interpretable as the interest rate

[9] Note that for any given macroeconomic statistic, the time series of surprises is mostly zeros, since each statistic is typically only released once per month (or in some cases once per quarter).

response to a one-standard-error surprise in the given data release. Our sample period runs from January 1990 through December 2002.

We select the variables to include in the regression based on their statistical significance in predicting the spot one-year Treasury yield (i.e., the one-year forward rate ending one year ahead). Specifically, we estimate the regression for the one-year yield using all 39 data surprises, drop the least significant one, and iterate in this manner until all the remaining variables (13 variables) are significant at the 1% level. [10]

The results are reported in Table 1. The effects of the macroeconomic surprises on the one-year yield all have the sign one would expect: when releases that are procyclical (such as Retail Sales) have a higher realized value than expected, the short-term interest rate increases and when countercyclical indicators (such as Initial Claims) turn out to be higher than expected, the one-year yield responds negatively. Similarly, data releases that pertain directly to near-term inflation (such as the CPI) generate interest rate responses in the same direction.

Of greater relevance to the current paper, though, is the fact that many of these variables also have a significant impact on one-year forward rates ending five and even ten years ahead. Eleven of the variables enter the regressions with significant coefficients (at the 10% level) for the five-year-ahead forward interest rate, and 10 variables enter significantly for the ten-year-ahead forward interest rate. This excess sensitivity of long rates is present both for indicators of inflation and factor costs (e.g., the core PPI and Employment Cost Index) and for indicators of output (e.g., GDP, Nonfarm Payrolls, Retail Sales). Moreover, in many cases the response of the long-term forward interest rate is only modestly smaller than the response of the spot one-year rate.

[10] We also included the core PPI in this set of variables, even though it did not enter significantly in the 1-year regressions, because it is very widely watched by financial markets (Fleming and Remolona (1997)) and enters significantly at longer horizons. The selection procedure in the text yields a set of variables that is very close to what one would obtain by other means, such as using a set of variables that are featured most prominently in the financial press, or using those variables whose releases lead to the most significant increases in bond-market trading volume (Fleming and Remolona (1997)). Using these alternative lists of variables does not alter our conclusions below.

In Figure 3, we present the same results graphically for nine of the most interesting macroeconomic data releases. In each panel of the figure, we plot the regression coefficients for the response of the one-year forward rate at each horizon from zero to fourteen years ahead, together with 95% confidence bands around that estimate. The persistence of the effects of many of these announcements on forward interest rates is remarkable, going out even 15 years in many cases.

This excess sensitivity is at odds with the predictions of the macroeconomic models considered above. Each of the data surprises included in the regressions presumably reflects some combination of the macroeconomic disturbances from that model. Thus, if one does not expect to find a sizable response of long-term interest rates to the models' shocks ε^{π} and ε^{y}, then one would not expect to find such a response to the news releases either.

Moreover, it should be emphasized that even though some of these statistics might be regarded as nonstationary (e.g., Nonfarm Payrolls or Retail Sales), their effect on interest rates in standard macroeconomic models should not be. Standard models express interest rates as a function of the output *gap,* rather than the level of output, and the former variable is typically regarded as stationary even though the latter may not be. Thus, a given shock to output may have permanent implications for the level of output, but the predicted effects for the output gap and interest rates will typically only be transitory. A similar observation can be made with respect to inflation—even though there is some evidence that inflation was nonstationary in the 1970s and early 1980s, so long as monetary policy follows the "Taylor principle" (raising real interest rates in response to an increase in inflation), both inflation and nominal interest rates will be mean-reverting in standard models. Empirical estimates of monetary policy reaction functions for the U.S. (e.g., Taylor, 1993 and CGG, 2000) indicate that the Fed has followed the "Taylor principle" over our sample, and thus we should generally observe short-term nominal interest rates returning to steady state in response to inflation shocks.

3.3. The Excess Sensitivity of Long-term Interest Rates to Monetary Policy Surprises

The preceding section demonstrated that long-term forward interest rates tend to track the short-term interest rate in response to disturbances that the models above would consider transitory. Macroeconomic data releases are important for interest rates presumably because they contain information about the future course of monetary policy. We next turn our attention to the most important data release for expectations of near-term monetary policy: FOMC policy decisions.

Unlike the other macroeconomic data releases we consider, we do not use survey measures of expectations about upcoming monetary policy decisions. Instead, we use prices of federal funds futures contracts, which provide a virtually continuous, market-based measure of these expectations, as noted by Krueger and Kuttner (1996), Rudebusch (1998), and Brunner (2000).[11] The federal funds futures contract for a given month has a payout based on the average effective federal funds rate during that month, so that daily changes reflect revisions to the federal funds rate expected to prevail over the remainder of the month. Thus, as explained in Kuttner (2001), the change in the current month's contract rate on the day of the FOMC meeting (or intermeeting policy action) can be used to calculate the unexpected component of policy actions, as follows:[12]

$$i_t - E_{t-1} i_t = (D/(D-d)) \cdot \Delta ff1_t \qquad (3.2)$$

where *d* is the day of the month on which the FOMC meeting (or intermeeting action) occurs, *D* is the total number of days in the month, and $\Delta ff1$ is the change in the rate on the current month's federal funds futures contract.

[11] Gürkaynak, Sack, and Swanson (2002) find that, among many financial market instruments that potentially reflect expectations of monetary policy, federal funds futures are the best predictor of future policy actions.

[12] Our measure of monetary policy surprises differs slightly from Kuttner's, in that we look at the next month's contract if an FOMC meeting takes place in the last seven days of a month, whereas Kuttner does this only if the meeting takes place in the last three days.

We compute the monetary policy shocks for all FOMC meetings and intermeeting policy actions since 1990. One small complication arises in the timing of the shocks: since 1994, the FOMC has explicitly announced its target for the federal funds rate on the afternoon of the FOMC meeting, while prior to 1994, the announcement of the target rate to the market was not explicit, but was effectively made through the size and type of open market operation the following morning. We take this change in timing into account in computing our monetary policy surprises.[13]

Having computed our monetary policy surprise series, we regress the daily change in forward interest rates around each FOMC announcement on the monetary policy surprise. Figure 4 presents the estimated response coefficients of one-year forward rates ending one to 15 years ahead, along with 95% confidence bands.

As expected, forward rates at the short end of the yield curve increase following a surprise tightening of the federal funds rate (and decrease following a surprise easing). Given that the federal funds rate typically has some persistence, as noted by many authors, tighter policy today leads to expectations that the federal funds rate will remain higher in the near future, thus pushing near-term forward rates in the same direction as the policy surprise.

However, at longer horizons, one-year forward rates actually move in the direction *opposite* to that of the policy surprise. The effect is statistically significant and long-lasting, going out as far as 15 years. Figure 5 illustrates this effect in a different way by plotting the change in the one-year forward rate ten years ahead against the surprise component of the monetary policy announcement.

The regression equation corresponding to Figure 5 is:[14]

---

[13] There are two other exceptions to this timing convention, as noted in Kuttner (2001), when a policy move by the FOMC was announced after the close of the federal funds futures market at 3:30pm.

[14] Regressions for the 1990-2002 and 1994-2002 samples are insensitive to removal of outliers, excluding intermeeting moves and using only dates with policy changes. The September 17, 2002 intermeeting easing is excluded from all samples as markets lacked the liquidity to be efficient indicators of policy expectations for several days prior to this date.

$$\Delta 10yrfwd = \underset{(0.60)}{-0.88} - \underset{(7.89)}{14.93}*surprise, \qquad R^2 = 0.06 \qquad N = 114$$

where heteroskedasticity-consistent standard errors are reported in parentheses. The coefficient on the monetary policy surprise is significant at the 10% level. Moreover, this finding seems to have strengthened in more recent samples: repeating this regression exercise for the 1994-2002 period, when our measure of the monetary policy surprise is arguably more accurate, yields the estimates:

$$\Delta 10yrfwd = \underset{(0.74)}{-0.75} - \underset{(10.06)}{20.22}*surprise. \qquad R^2 = 0.10 \qquad N = 76$$

For this later sample, the regression coefficient is significant at the 5% level.

Our finding that long-term forward rates move in the direction *opposite* to monetary policy surprises stands in sharp contrast to conventional wisdom in the literature. For example, Romer and Romer (2000) and Cook and Hahn (1989) seem to come to exactly the opposite conclusion: "When the Federal Reserve undertakes contractionary open market operations, interest rates for securities of all maturities typically rise" (Romer and Romer, p. 429). The primary difference between their analysis and ours is that they consider long-term *yields*—which *do* move slightly in the same direction as short rates in response to a monetary policy surprise—instead of long-term *forward rates,* which is a more correct measure for investigating excess sensitivity.[15] It should also be noted that these earlier authors' measures of monetary policy surprises suffer from measurement error, since they use only the raw change in the federal funds rate target, effectively treating each policy action by the FOMC as having been completely unexpected by the markets. Kuttner (2001) shows that, not surprisingly, it is the unexpected component of FOMC policy actions that are related to term structure movements, rather than the raw policy actions themselves.

[15] We verify below that our findings are not an artifact of fitting a smooth yield curve to the Treasury market data by replicating our results using STRIPS data, which are pure zero-coupon, risk-free U.S. government securities.

As with the macroeconomic surprises, our finding is inconsistent with the economic models considered above, which would view monetary policy shocks (corresponding to the shock term ε_t^i in the model) as transitory movements away from the steady state that would warrant no response of long-term forward rates. Moreover, the fact that monetary policy surprises cause long-term forward rates to move in the direction *opposite* to short-term rates—in contrast to surprises in all of our macroeconomic data releases—provides an important clue about the source of the shocks. However, before turning to possible explanations for our empirical findings in the next section, we first check the robustness of the findings to an alternative method for computing forward rates.

3.4 Robustness Check: STRIPS-based Forward Rates

Forward rates can only be directly derived from the yields (or prices) of zero-coupon securities. To compute the forward rates used above, we made use of a smoothed zero-coupon yield curve estimated from the prices of Treasury notes and bonds. However, it is conceivable that the smoothing involved in fitting the yield curve forces a relationship between short-term and long-term interest rates, thereby leading to a spurious finding of excess sensitivity of long forward rates.

To make sure that this is not the case, we repeat our analysis using forward rates derived directly from Treasury STRIPS. STRIPS are zero-coupon securities created from the individual payments on Treasury notes and bonds that trade in the market like other Treasury securities.[16] By relying on STRIPS, we can obtain a purely market-based reading of forward rates that does not require any smoothing.[17]

More specifically, we compute the forward rates from coupon STRIPS with maturities that are one year apart and that most closely span the period covered by the forward rate.

---

[16] See Sack (2000) for more details on Treasury STRIPS and their potential use in estimating the Treasury yield curve.

[17] The downside of this approach is that STRIPS at some maturities are less liquid than Treasury notes and bonds. As a result, the yields on those securities might have some idiosyncratic variation, which imparts some noise into the STRIPS-based forward rates.

As above, we consider the one-year forward rates ending in five and ten years, but omit the forward rate ending in one year because of a lack of data. The sample here begins in 1994, when reliable STRIPS data are first available to us.

Repeating the analysis from above, we once again find that these long-term forward rates react significantly to many of the macroeconomic data releases, as reported in Table 2 (which is analogous to Table 1). As can be seen, 10 of the 13 macroeconomic surprises affect five-year ahead forward rates and ten-year forward rates significantly. The magnitudes are once again comparable to magnitudes reported in Table 1.

Moreover, when we look at the response of the ten-year-ahead STRIPS-based forward rate to monetary policy surprises, we once again find a negative relationship:

$$\Delta 10yrfwd = \underset{(0.72)}{-0.75} + \underset{(8.16)}{-30.05}*surprise \qquad R^2 = 0.18 \qquad N = 73.$$

The coefficient is a bit larger in magnitude than that found above for the 1994-2002 period, and it is even more statistically significant (now significant at the 1% level).

Overall, then, the finding that long-term forward rates demonstrate excess sensitivity to the various disturbances considered in this section appears to be robust. We now turn to potential explanations of this behavior.

4. Possible Explanations for the Behavior of Long-term Interest Rates

In steady state, the short-term nominal interest rate *i* equals the steady-state real interest rate r* plus the steady-state level of inflation π*, by Fisher's equation:

$$i^* = r^* + \pi^* \qquad (4.1)$$

As mentioned above, standard asset-pricing theory indicates that forward rates with sufficiently long horizons (i.e., $f_t(N,1)$ for N large) equal the expected steady-state short-term rate plus a risk premium ρ:

$$f_t(N,1) = r^* + \pi^* + \rho \tag{4.2}$$

The fact that $f_t(N,1)$ responds to many macroeconomic data releases and monetary policy surprises seems to indicate that one (or more) of r*, π*, and ρ is changing in response to these surprises.

4.1. Some Non-explanations for the Excess Sensitivity Puzzle

4.1.1. Persistent Transitory Shocks

Of course, one could argue that the five- to 15-year horizon that we consider in our empirical analysis is simply not long enough for short-term interest rates in the U.S. to return to their steady-state levels. The problem with this explanation is that realistic calibrations of macroeconomic models to the data usually imply that interest rates return to steady state within just a few years, typically much fewer than the 10-year lag that would be required to support this explanation.

In section 2, we presented interest rate impulse response functions from two baseline macroeconomic models as examples. We now try increasing the persistence in these models by raising the persistence of the exogenous driving shocks as a robustness check. Figure 6 presents the results. In both models, we assume that the exogenous shocks to the inflation and output gap equations have an AR(1) persistence coefficient of 0.8, implying that these shocks have a half-life of about 3 quarters (above and beyond any endogenous persistence that is generated by the dynamics of the model). In both cases, the effects of shocks to the model on interest rates continue to die out well within 10 years.

In order to generate persistence in these models sufficient to account for the excess sensitivity of long-term interest rates that we see in the data, we would require AR(1) coefficients on inflation and output gap shocks of about 0.95, implying a half-life for these exogenous shocks of over 13 quarters, or more than 3 years (remember that this is not including any endogenous persistence generated by the model)! Even then, we would not be able to account for the excess sensitivity of long-term interest rates to monetary policy announcements without assuming a similarly large persistence of exogenous shocks to the short-term interest rate. We view such a high degree of shock persistence in these models as empirically implausible and theoretically unfounded.

*4.1.2. Changes in r**

One might accept our hypothesis that one or more of r*, π*, and/or ρ is changing in response to macroeconomic and monetary policy surprises, but argue that changes in the steady-state real rate of interest r* is the most likely explanation for our excess sensitivity findings. The primary problem with this argument is that interest rate responses to some of the surprises we consider are the opposite of what changes in r* would typically require. For example, it is difficult to explain why a surprise uptick in inflation (the CPI or PPI) would lead the market to revise upward its estimate of r*, the long-run equilibrium *real* rate of interest. Similarly, it is difficult to explain why a surprise monetary policy tightening would lead the market to revise *downward* its estimate of r*—presumably a surprise tightening of policy, to the extent that it provides any information about r*, indicates that the FOMC views r* as being *higher* than the market estimate.

Moreover, if changes in r* were responsible for all of our results, then presumably we would find similar results for U.S. inflation-indexed (i.e., TIPS) interest rates and for long-term interest rates in the U.K. In fact, as we show in section 5, below, we do not find such movements in these other interest rates. We regard this as additional supporting evidence that changes in r* are not driving our empirical findings.

This is not to say that changes in the market's perception of r* are necessarily unimportant. Indeed, it is possible that changes in r* did have some effect on long-term interest rates in our sample, particularly in the late 1990s, when market estimates of the long-run rate of productivity growth in the U.S. were largely in flux. Relying solely on changes in r* to explain our empirical results, however, is likely to run into difficulties along the dimensions we have described above.

4.1.3. Changes in Risk Premia ρ

Alternatively, one might argue that changes in the risk premium ρ are the most likely explanation for our findings of excess sensitivity in long-term interest rates. Indeed, a time-varying risk premium is often offered as an explanation for the excess volatility puzzle and as a likely factor in the failure of the expectations hypothesis for longer maturities.

There are a number of difficulties with relying on time-varying risk premia to explain our results, however. First, as shown in section 5 below, we do not find similar movements in U.S. inflation-indexed debt (TIPS) or in long-term interest rates in the U.K. once the Bank of England gained independence. Thus, to the extent that risk premia can explain our findings, those risk premia do not seem to be related to uncertainty about real interest rates or other macroeconomic variables, such as GDP or aggregate consumption, since uncertainty about these variables would presumably affect risk premia for real interest rates as well as nominal rates, and risk premia in the U.K. as well as in the U.S. In order to explain our empirical findings, changes in risk premia around the events we consider would have to be very closely linked to inflation risk.

Distinguishing between changes in the "inflation risk premium" and changes in the long-run expected rate of inflation π^*, however, is inherently difficult—one can think of it as trying to distinguish between changes in the mean of the long-run inflation rate vs.

changes in the higher moments of the distribution surrounding that variable.[18] Our data by themselves do not allow us to make such a fine distinction, but Ang and Bekaert (2003) consider this question in an affine term structure model with regime switching, and, under the assumption that changes in inflation risk at very short (one-quarter-ahead) horizons are negligible, conclude that the large majority of movements in long-term nominal interest rates is due to changes in expected inflation rather than to changes in inflation risk premia. We regard this as justification for focusing on changes in expected long-run inflation π^* rather than inflation risk in what follows.

4.2. A Possible Explanation for Excess Sensitivity: Changes in π^*

While we do not wish to overly discount the importance of changes in market expectations of r^* or changes in the market price of non-inflation-related risk, we find each of them inadequate on its own to explain all of our empirical results. However, there is one explanation that *is* potentially consistent with all of our empirical findings: changes in the market's perception of π^*, the steady-state inflation rate.

We can demonstrate this in the baseline models from section 2 by augmenting the models to include an additional equation that permits the long-run level of inflation π^* to vary over time. We do not take a stand on why this might be so: for instance, it may be that, after a shock, the central bank views the costs of driving inflation π_t all the way back to its original π^* as being larger than the benefits. Alternatively, it may be that private agents' long-run expectations of inflation π^* tend to drift over time, and the central bank is maximizing the welfare of its citizens.[19] Regardless of the source of the variation in π^*, we consider a specification in which the central bank's long-run target for inflation displays some dependence on past values of π, i.e.:

[18] In addition, for many practical questions of interest, distinguishing between these two effects of inflation on long-term interest rates may be of secondary importance, so long as it is known that inflation as a whole is responsible.

[19] One would have to assume here that small changes in the steady-state rate of inflation are relatively costless (e.g., due to indexation), while transition costs involved in changing the public's expectations are more substantial.

$$\pi_t^* = \pi_{t-1}^* + \theta(\bar{\pi}_{t-1} - \pi_{t-1}^*) + \varepsilon_t^{\pi^*} \tag{4.3}$$

where $\bar{\pi}_{t-1}$ is the trailing four-quarter moving average of inflation. Thus, low inflation will, after a while, tend to decrease the central bank's long-run inflation target.

Moreover, we assume that the central bank's inflation target π* is not directly observed by the private sector, and thus must be inferred by agents on the basis of the central bank's actions, as in Ellingsen and Soderstrom (2002), Kozicki and Tinsley (2001a), and Erceg and Levin (forthcoming). This allows the model to capture the possibility that a surprise monetary tightening may indicate to agents that the central bank's long-run target for inflation has fallen. Exogenous changes in the central bank's inflation target π* are captured by the shock $\varepsilon_t^{\pi^*}$.

Our baseline model with time-varying π* thus takes the form:

$$\pi_t = \mu E_t \pi_{t+1} + (1-\mu) A_\pi(L) \pi_t + \gamma y_t + \varepsilon_t^\pi \tag{4.4}$$

$$y_t = \mu E_t y_{t+1} + (1-\mu) A_y(L) y_t - \beta(i_t - E_t \pi_{t+1}) + \varepsilon_t^y \tag{4.5}$$

$$i_t = (1-c)\left[\bar{\pi}_t + a(\bar{\pi}_t - \pi_t^*) + b y_t\right] + c\, i_{t-1} + \varepsilon_t^i \tag{4.6}$$

$$\pi_t^* = \pi_{t-1}^* + \theta(\bar{\pi}_{t-1} - \pi_{t-1}^*) + \varepsilon_t^{\pi^*} \tag{4.7}$$

$$\hat{\pi}_t^* = \hat{\pi}_{t-1}^* + \theta(\bar{\pi}_{t-1} - \hat{\pi}_{t-1}^*) - \kappa(i_t - \hat{i}_t) \tag{4.8}$$

For simplicity and tractability, we assume that the forms of equations (4.4) through (4.7), all parameter values, and the shocks ε^π and ε^y are perfectly observed by the private sector. Thus, only π*, ε^{π^*}, and ε^i are unobserved. The private sector's Kalman filtering problem then takes on the simple form (4.8), where $\hat{\pi}_t^*$ denotes private agents' estimate of the central bank's inflation target and the parameter κ denotes the private sector's Kalman gain on deviations of the interest rate from agents' expectation based on their prior estimate of π*.

Figure 7 presents impulse response functions for the time-varying π^* version of our baseline models to each of the shocks ε in equations (4.4) through (4.7). We first present the results from the partially backward-looking Rudebusch model. Parameter values are the same as in section 2, and we set θ=0.02, κ=0.1 to calibrate our impulse response functions roughly to the data. Each column of Figure 7 presents the impulse responses of inflation, the output gap, the short-term interest rate, the central bank's long-run inflation target π^*, and the private sector's estimate of π^*, respectively, to a given shock. The first column presents the responses to a one-percent shock to the inflation equation (ε^{π}), the second column the responses to a one-percent shock to the output gap equation (ε^{y}), and so on.

The qualitative features of our empirical findings are reproduced very nicely. For example, after an inflation shock, the short-term nominal interest rate rises gradually, peaks after a few years, and then returns to a long-run steady-state level that is about 35 basis points higher than the original steady state. This is due to the fact that the higher levels of inflation on the transition path lead the central bank's long-run target π^* to rise somewhat as a result. A similar response of short-term nominal interest rates and inflation can be seen in response to a shock to a one-percent shock to output.

For the federal funds rate shock, two effects are present. First, when the private sector sees the surprise tightening in short-term interest rates, they respond by partially revising downward their estimate of the central bank's target π^*. Second, as inflation in the economy falls in response to both the monetary tightening and the fall in expectations of inflation, the central bank's long-run target π^* begins to fall as well. In the long run, the short-term nominal interest rate and inflation return to lower levels than where they began.

Finally, in response to a direct, exogenous shock to the central bank's long-run target π^* (depicted in the fourth column as an exogenous one-percent *reduction* in the central bank's inflation target), the private sector gradually revises its estimate of the central bank's inflation target downward. In the end, inflation and the short-term nominal interest rate are significantly lower than their original steady-state values.

Note that learning and imperfect information about the central bank's target, π^*, play a role only in the third and fourth columns of the figure, and not in the first two columns. Thus, a model based solely on learning or "imperfect credibility" (as in Kozicki and Tinsley (2001a,b) or Erceg and Levin (forthcoming)) would *not* be able to reproduce our findings of excess sensitivity of long-term rates in response to output and inflation surprises.

For completeness, we have also included the analogous set of impulse response functions for the CGG model in Figure 7 (on the following page). The predictions of the CGG model are qualitatively similar to those of the Rudebusch model, though the CGG model fits the short-run dynamics of the data less well (in fact, we have included the AR(1) persistence coefficient of 0.8 for the inflation and output shocks in this version of the model, to better match these short-run aspects of the data). Note that, because the impulse response functions for inflation are less persistent for this model than in the Rudebusch version, we require a higher value of θ to match the data; in the figure presented here, we use a value of θ=0.1, which is five times higher than the value we used in the more inertial Rudebusch model.

Thus, our empirical observations all seem to be consistent with a simple modification of our baseline models that allows for time-varying long-run inflation expectations π^*. Of course, one could always make additional modifications to the model to capture additional features of the economy one deemed important—e.g., one might hypothesize that the central bank's long-run target π^* is actually fixed over time, and it is simply the public that temporarily, mistakenly *believes* that this target varies over time; or that the public simply believes there is some probability greater than zero (but less than one) that the central bank will not drive inflation after a shock all the way back to the previous long-run target π^*. We leave these avenues for future research.

Our hypothesis that the private sector's expectations of long-run inflation π^* have varied over time is also consistent with measures of these expectations derived from survey data. For example, the median 10-year-ahead CPI inflation forecast in the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters has fallen from a little over 4 percent in 1991 (the first year the long-run forecast question was asked) to a little under 2½ percent by the end of 2002. This decline of about 160 basis points compares with a fall of about 260 basis points in 10-year nominal forward interest rates over the same period. We next turn to empirical evidence that markets' long-term inflation expectations have also varied systematically in response to macroeconomic and monetary policy surprises.

5. *Evidence from Treasury Inflation-Indexed Debt*

The hypothesis that movements in long-term forward rates are driven primarily by expected inflation and not expected real interest rates can be tested directly when a market-based measure of real interest rates is available. An obvious source of such a measure is the market for Treasury inflation-indexed securities, which are commonly referred to as TIPS. Because their coupon and principal payments increase in line with CPI inflation, the quoted yields on TIPS approximately represent the real return that an investor would realize from holding the security to maturity. Hence, those yields can be used to compute real forward rates, or the real rate of return that an investor can lock in today for some future period.

A complication arises because there are not enough securities to estimate a reliable zero-coupon yield curve for TIPS. In the following results, we use an approximation to compute one-year real forward rates using the two most recently issued ten-year TIPS. In particular, we assume that the yields on those two securities are approximately equal to the yields that investors would demand for zero-coupon inflation-indexed securities with the same duration as the TIPS. In that case, we can compute the real one-year forward rate ending at the duration of the most-recently-issued ten-year TIPS.

Because such securities are typically issued only once a year, the horizon covered by the real forward rate varies over time. That is, it is at its longest when a new security is issued, and it narrows by a year until just before a new security is issued. In order to make comparisons of the real forward rate to its nominal counterpart, we recomputed the nominal one-year forward rate for the exact horizon covered by the real forward rate on each date.

The primary difficulty in using TIPS, and the reason that we did not rely on this approach earlier, is that the TIPS market has only existed for about six years. Ten-year TIPS have been issued every January since 1997 (and in July 2002), which allows us to compute a real one-year forward rate only since January 1998. Thus, given the limited number of data points, the results must be taken with caution at this point.

The estimated responses to macroeconomic surprises are shown in Table 3. Because the sample is shorter, we again show the response of the one-year nominal rate, which is now significant for nine of the macroeconomic variables. Seven variables also generate a significant response of the long-term nominal forward rate. The real forward rate responds marginally significantly to two variables, and this is due to a single influential observation in both cases. The response of the long-term nominal rate is more often generated by its inflation compensation component than by its real component. Indeed, inflation compensation responds significantly for four of the seven variables. Importantly, while the small number of observations diminishes the precision of the estimates, the coefficients for inflation compensation are similar in magnitude to coefficients for the long-term nominal rate whereas the coefficients for real rates are mostly very small, and many times have the wrong sign.

Table 4 repeats the same exercise for the monetary policy shocks. We find that the real long-term forward rate does not respond to monetary policy shocks, while inflation compensation responds with a significant negative coefficient. Thus, it appears that the response of expected inflation drives the negative relationship between policy shocks and nominal forward rates noted above.[20]

6. Evidence from the U.K

The evidence presented from U.S. financial markets suggests that forward rates are unanchored in part because the Federal Reserve does not have an absolute commitment to a specific, known inflation target. This possibility immediately raises the question of whether similar behavior is observed in countries that have announced explicit targets for inflation. We investigate this question by looking at the response of forward rates in the U.K. to macroeconomic news.

The U.K. adopted an inflation target in 1992, but at this time the Bank of England lacked independence. The Bank of England gained operational independence in mid-1997, and the credibility of its commitment to the specified inflation target greatly increased at that time. Against this background, one might expect to see long-term forward rates in the U.K. responding much more strongly to macroeconomic news in the 1992-1997 period than in the period since the Bank of England gained independence in mid-1997.

To test this hypothesis, we carry out an exercise for the U.K. similar to the one performed above using U.S. data. In particular, we look at the response of forward rates at different horizons to various macroeconomic surprises. The surprises are again computed using survey measures from MMS, although we restrict the analysis to a more limited set of macroeconomic variables. Based on the availability of MMS data to us, our sample covers the period from February 1993 to August 2001.

[20] Interestingly, in our short sample, the response of the nominal forward rate is insignificant, reflecting the positive coefficient on the real forward rate and the negative coefficient on inflation compensation. The coefficients have the expected signs for both short-and long-horizons but they are estimated imprecisely.

The findings are reported in Table 5. In the pre-independence period, four of the six macroeconomic variables considered had a significant impact on the one-year interest rate. Of those four, three of the variables also generated significant responses of the forward rates ending five and ten years ahead. This finding suggests that long-term inflation expectations were not well anchored in the U.K. over this period. As in the U.S. data, the response of forward rates occurred in response to both direct news about inflation, including RPI (retail price) inflation and PPI (producer price) inflation, and to news about the strength of aggregate demand (the preliminary GDP release).

This behavior appears to have shifted in the post-independence period. As above, we find that four of the variables considered have significant effects on the one-year rate, but now none of those four have any explanatory power for forward rates ending five or ten years ahead. In other words, the expected impact on the short-term interest rate appears to be transitory in response to these shocks—the pattern that one would expect to find if long-run inflation expectations are well anchored by the inflation target.

Of course, such conclusions are tentative given the limited number of data points available to us. Nevertheless, in combination with the evidence from U.S. financial markets presented above, these findings lend support to the view that variation in the perceived long-run inflation target of the Federal Reserve accounts for some of the excess sensitivity of long-term forward rates.

7. Conclusions and Implications

This paper has presented evidence that forward rates at long horizons react significantly to a variety of macroeconomic and monetary policy surprises that would be expected to have only transitory effects on the short-term interest rate under standard macroeconomic models. In particular, the empirical evidence is at odds with the modeling assumption that the long-run properties of the economy are constant and perfectly known by all agents. We argue that the most plausible explanation for the observed term structure behavior is that the private sector has adjusted its expectations of the long-run level of inflation to these macroeconomic and monetary policy surprises.

Such a conclusion might have important implications for the macroeconomic models themselves. Not only would those models have difficulty capturing the long-run properties of the economy, but any misspecification of those long-run properties would also affect their short-run predictions as well. For example, the models considered are calibrated to match the dynamics of inflation at business cycle frequencies, under the assumption that long-run inflation expectations are perfectly anchored. To the extent that this assumption is violated, the short-run dynamics of inflation would be misspecified, and estimates of the parameters governing those dynamics would be incorrect.

Our findings may also have important implications for the conduct of monetary policy. Although our results suggest that inflation expectations in the U.S. have responded to these macroeconomic surprises, the Federal Reserve has achieved remarkable economic performance—and inflation expectations have fallen to very low levels—over our sample period. Nevertheless, to the extent that there may be benefits to stabilizing long-run forward rates and inflation expectations, our results suggest that there is some scope for improvement. Moreover, our results for the U.K., while based on a limited amount of data, seem to indicate that the central bank can help stabilize long-term forward rates and inflation expectations by credibly committing to an explicit inflation target.

8. References

Ang, Andrew and Geert Bekaert. "The Term Structure of Real Rates and Expected Inflation," unpublished manuscript, Columbia Business School (2003).

Brunner, Allan D. "On the Derivation of Monetary Policy Shocks: Should We Throw the VAR Out with the Bath Water?" Journal of Money, Credit, and Banking (May 2000), v. 32 (2), pp. 254-79.

Clarida, Richard, Jordi Gali, and Mark Gertler. "The Science of Monetary Policy: A New Keynesian Perspective." Journal of Economic Literature (December 1999), v. 37 (4), pp. 1661-1707.

Cook, Timothy and Thomas Hahn. "The Effect of Changes in the Federal Funds Rate Target on Market Interest Rates in the 1970s," Journal of Monetary Economics (November 1989), v. 24 (3), pp. 331-51.

Ellingsen, Tore and Ulf Soderstrom. "Monetary Policy and Market Interest Rates." American Economic Review (December 2001), 91 (5), pp. 1594-1607.

Erceg, Christopher and Andrew Levin. "Imperfect Credibility and Inflation Persistence," Journal of Monetary Economics (forthcoming).

Estrella, Arturo and Jeffrey Fuhrer. "Dynamic Inconsistencies: Counterfactual Implications of a Class of Rational Expectations Models." American Economic Review (2002).

Fisher, Mark, Douglas Nychka, and David Zervos. "Fitting the Term Structure of Interest Rates With Smoothing Splines." Federal Reserve Board Finance and Economics Discussion Series 95-01 (January 1995).

Fleming, Michael and Eli Remolona. "What Moves the Bond Market?" Federal Reserve Bank of New York Economic Policy Review (December 1997), pp. 31-50.

Fuhrer, Jeffrey C. "The (Un)Importance of Forward-Looking Behavior in Price Specifications." Journal of Money, Credit, and Banking (August 1997), v. 29 (3), pp. 338-50.

Gürkaynak, Refet, Brian Sack, and Eric Swanson. "Market-Based Measures of Monetary Policy Expectations." Federal Reserve Board Finance and Economics Discussion Series 2002-40 (2002).

Knez, Peter, Robert Litterman, and Jose Scheinkman. "Explorations into Factors Explaining Money Market Returns." Journal of Finance (December 1994), v. 49 (5), pp. 1861-82.

Kozicki, Sharon and Peter Tinsley. "What Do You Expect? Imperfect Policy Credibility and Tests of the Expectations Hypothesis," Federal Reserve Bank of Kansas City Research Working Paper RWP 01-02 (2001a).

Kozicki, Sharon and Peter Tinsley. "Shifting Endpoints in the Term Structure of Interest Rates," Journal of Monetary Economics (June 2001b), v. 47 (3), pp. 613-52.

Krueger, Joel T. and Kenneth N. Kuttner. "The Fed Funds Futures Rate as a Predictor of Federal Reserve Policy." Journal of Futures Markets (December 1996), v. 16 (8), pp. 865-79.

Kuttner, Kenneth N. "Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market." Journal of Monetary Economics (June 2001), v. 47 (3), pp. 523-44.

Roberts, John M. "Is Inflation Sticky?" Journal of Monetary Economics (July 1997), v. 39 (2), pp. 173-96.

Romer**,** Christina D. and David H. Romer. "Federal Reserve Information and the Behavior of Interest Rates," American Economic Review (June 2000), v. 90 (3), pp. 429-57.

Rudebusch, Glenn. "Do Measures of Monetary Policy in a VAR Make Sense?" International Economic Review (November 1998), v. 39 (4), pp. 907-31.

Rudebusch, Glenn. "Is the Fed Too Timid? Monetary Policy in an Uncertain World." Review of Economics and Statistics 83 (May 2001), pp. 203-17.

Rudebusch, Glenn. "Term Structure Evidence on Interest Rate Smoothing and Monetary Policy Inertia." Journal of Monetary Economics 49 (September 2002), pp. 1161-87.

Sack, Brian. "Using Treasury STRIPS to Measure the Yield Curve." Finance and Economics Discussion Series working paper #2000-42 (2000).

Shiller, Robert J. "The Volatility of Long-Term Interest Rates and Expectations Models of the Term Structure" Journal of Political Economy (December 1979), v. 87 (6), pp. 1190-1219.

Svensson, Lars E. O. "Estimating and Interpreting Forward Interest Rates: Sweden 1992-1994." Centre for Economic Policy Research Discussion Paper 1051 (October 1994).

Table 1
Response of Forward Rates to Macroeconomic News

	---Ending 1 yr. ahead---		--- Ending 5 yr. ahead---		---Ending 10 yr. ahead---	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-0.12	0.08	-0.04	0.12	0.01	0.12
Capacity Utilization	1.53	0.38 ***	1.29	0.58 **	0.78	0.62
Consumer Confidence	2.03	0.40 ***	2.85	0.56 ***	1.97	0.54 ***
CPI (Core)	1.67	0.42 ***	1.80	0.60 ***	1.07	0.66 *
Employment Cost Index	3.14	0.81 ***	4.05	1.03 ***	3.41	0.85 ***
GDP (Advance)	4.74	1.49 ***	4.38	2.33 *	3.98	1.94 **
Initial Claims	-0.81	0.25 ***	-0.81	0.29 ***	-0.61	0.27 **
Leading Indicators	0.94	0.34 ***	0.62	0.58	0.56	0.59
NAPM	2.92	0.50 ***	3.19	0.52 ***	1.49	0.61 **
New Home Sales	1.07	0.39 ***	1.62	0.52 ***	0.89	0.50 *
Non-farm Payrolls	5.07	0.57 ***	3.47	0.91 ***	1.87	0.97 **
PPI (Core)	0.33	0.41	1.11	0.50 **	1.33	0.45 ***
Retail Sales	3.09	0.72 ***	2.58	1.02 **	1.85	0.91 **
Unemployment Rate	-1.81	0.52 ***	-0.79	0.75	0.15	0.67

Huber-White standard errors. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The estimated coefficient indicates basis point response of the one-year forward rate per standard deviation of the macroeconomic variable.

Table 2

Response of STRIPS-based Forward Rates to Macroeconomic News

	---Ending 5 yr. Ahead---		---Ending 10 yr. Ahead---	
	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-0.07	0.21	-0.01	0.17
Capacity Utilization	2.05	0.91 **	1.37	0.79 *
Consumer Confidence	3.82	1.77 **	1.16	0.63 *
CPI (Core)	2.86	1.22 **	1.75	1.06 *
Employment Cost Index	3.76	1.70 **	3.92	1.22 ***
GDP (Advance)	5.66	2.48 **	5.14	2.69 *
Initial Claims	-1.29	0.46 ***	-0.23	0.50
Leading Indicators	2.02	1.30	0.06	0.80
NAPM	5.23	1.07 ***	2.73	0.80 ***
New Home Sales	0.86	0.90	1.31	0.71 *
Non-farm Payrolls	3.51	0.85 ***	1.93	1.18 *
PPI (Core)	-0.06	0.87	1.27	0.63 **
Retail Sales	5.24	1.49 ***	2.05	1.14 *
Unemployment Rate	-1.98	0.89 **	0.00	1.19

Huber-White standard errors. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The estimated coefficient indicates basis point response of the one-year forward rate per standard deviation of the macroeconomic variable.

Table 3
Response of Real Forward Rates and Inflation Compensation to Macroeconomic News

	Nominal Rate Ending 1 yr. Ahead		--- Long-term Forward Rates --- Nominal		Real		Inflation Compensation	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-0.25	0.14 *	-0.05	0.18	0.09	0.15	-0.14	0.21
Capacity Utilization	2.80	0.90 ***	1.43	0.97	-0.08	0.50	1.51	1.05
Consumer Confidence	2.42	0.74 ***	1.79	0.85 **	-0.16	0.65	1.95	0.70 ***
CPI (Core)	0.06	0.87	1.52	1.11	0.71	0.89	0.81	1.33
Employment Cost Index	2.44	0.81 ***	2.11	0.84 ***	-0.10	0.89	2.22	1.05 **
GDP (Advance)	4.68	1.47 ***	4.40	1.91 **	1.91	1.59	2.50	1.85
Initial Claims	-1.23	0.47 ***	-0.83	0.40 **	-0.27	0.31	-0.55	0.39
Leading Indicators	0.27	0.64	1.15	0.83	0.77	0.66	0.38	0.82
NAPM	2.83	1.15 **	3.07	0.88 ***	1.87	1.02 *	1.20	1.17
New Home Sales	0.52	0.83	1.68	0.96 *	-0.35	0.54	2.03	0.89 **
Non-farm Payrolls	3.25	0.64 ***	0.35	0.99	1.61	0.85 *	-1.26	1.13
PPI (Core)	-0.95	0.83	0.03	0.69	0.41	1.12	-0.38	1.46
Retail Sales	4.82	1.12 ***	5.67	1.36 ***	0.59	1.23	5.08	1.67 ***
Unemployment Rate	-2.05	0.71 ***	-0.23	0.92	1.15	0.97	-1.39	1.11

Huber-White standard errors. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The estimated coefficient indicates basis point response of the one-year forward rate per unit of the macroeconomic variable.

Table 4
Response of Real Forward Rates and Inflation Compensation to Monetary Policy Surprises

	Nominal Rate Ending 1 yr. Ahead		--- Long-term Forward Rates --- Nominal		Real		Inflation Compensation	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-1.89	0.81 **	-0.96	0.74	-0.03	0.71	-0.92	0.79
Policy Surprise	22.83	14.81	-16.25	12.41	4.90	4.53	-21.15	9.56 **
Obs.	44		44		44		44	
R^2	0.13		0.10		0.02		0.16	

Huber-White standard errors. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 5
Response of U.K. Forward Rates to Macroeconomic News

Pre-Independence:

	---Current---		---5 yrs. Ahead---		---10 yrs. Ahead---	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-0.37	0.18 **	-0.06	0.18	-0.01	0.20
PPI (Input)	2.07	0.65 ***	1.87	1.17 *	2.26	0.95 **
RPI (Core)	-0.07	1.85	-4.46	3.03	-5.00	3.54
RPI	2.76	0.80 ***	3.54	0.87 ***	3.31	1.00 ***
Avg. Earnings	2.95	1.02 ***	1.24	0.94	0.50	0.87
GDP (Prelim)	1.98	1.21 *	2.12	0.79 ***	2.77	1.14 **
Mfg. Output	0.80	0.64	0.05	0.78	0.11	0.90

Post-Independence:

	---Current---		---5 yrs. Ahead---		---10 yrs. Ahead---	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	-0.20	0.11 *	-0.21	0.16	-0.25	0.15
PPI (Input)	-0.12	0.98	-0.19	0.97	-0.51	1.15
RPI (Core)	2.28	1.02 **	0.07	1.21	-0.43	0.92
RPI	0.80	1.17	0.09	1.31	-1.16	0.85
Avg. Earnings	2.53	0.64 ***	1.21	0.85	-0.39	0.74
GDP (Prelim)	2.05	0.58 ***	0.26	1.02	-1.08	1.41
Mfg. Output	1.28	0.62 **	1.02	0.88	0.14	0.95

Huber-White standard errors. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The estimated coefficient indicates basis point response per standard deviation of the macroeconomic variable.

Figure 1: Impulse Response Functions for Standard Macro Models

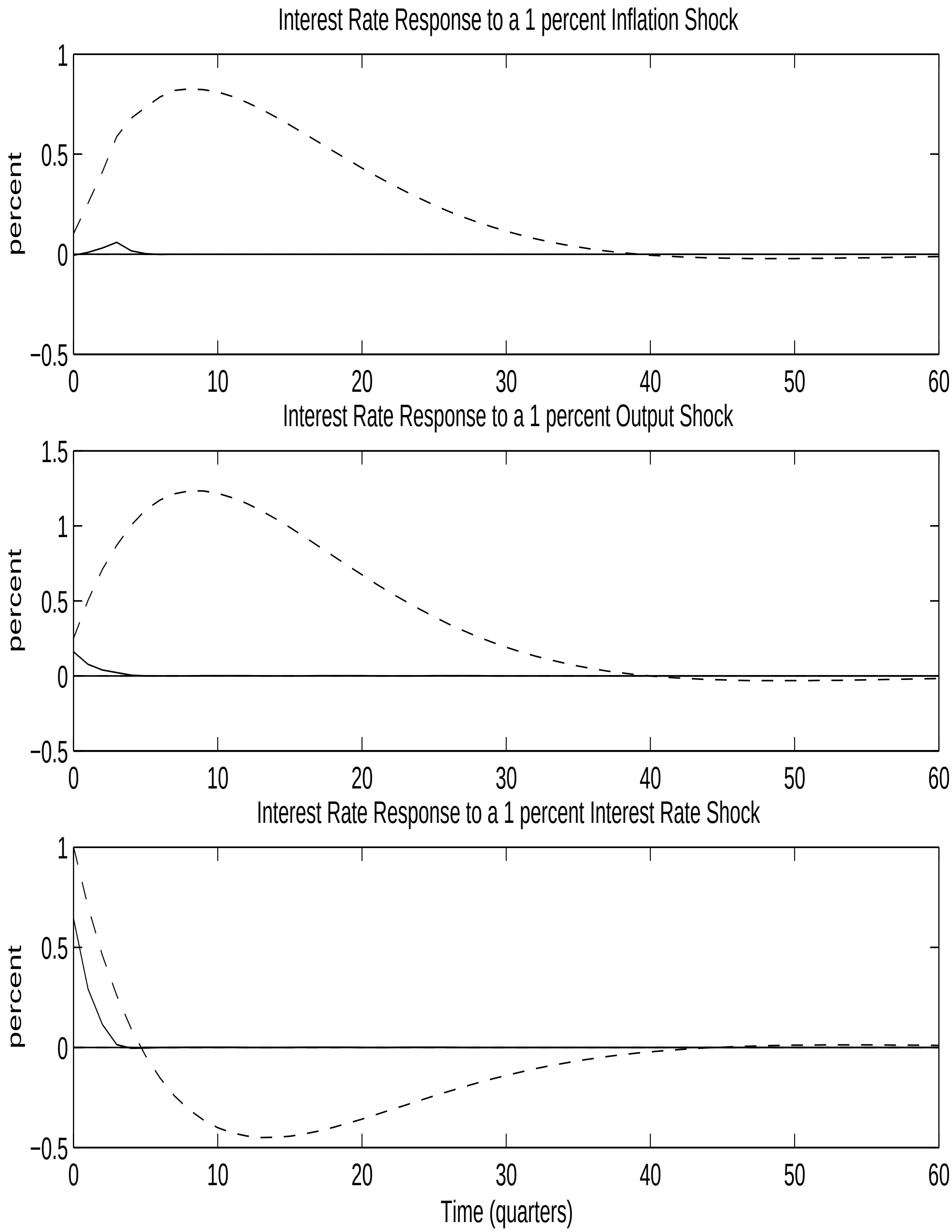

Figure 2: Simulated and Actual Volatility of Forward Rates

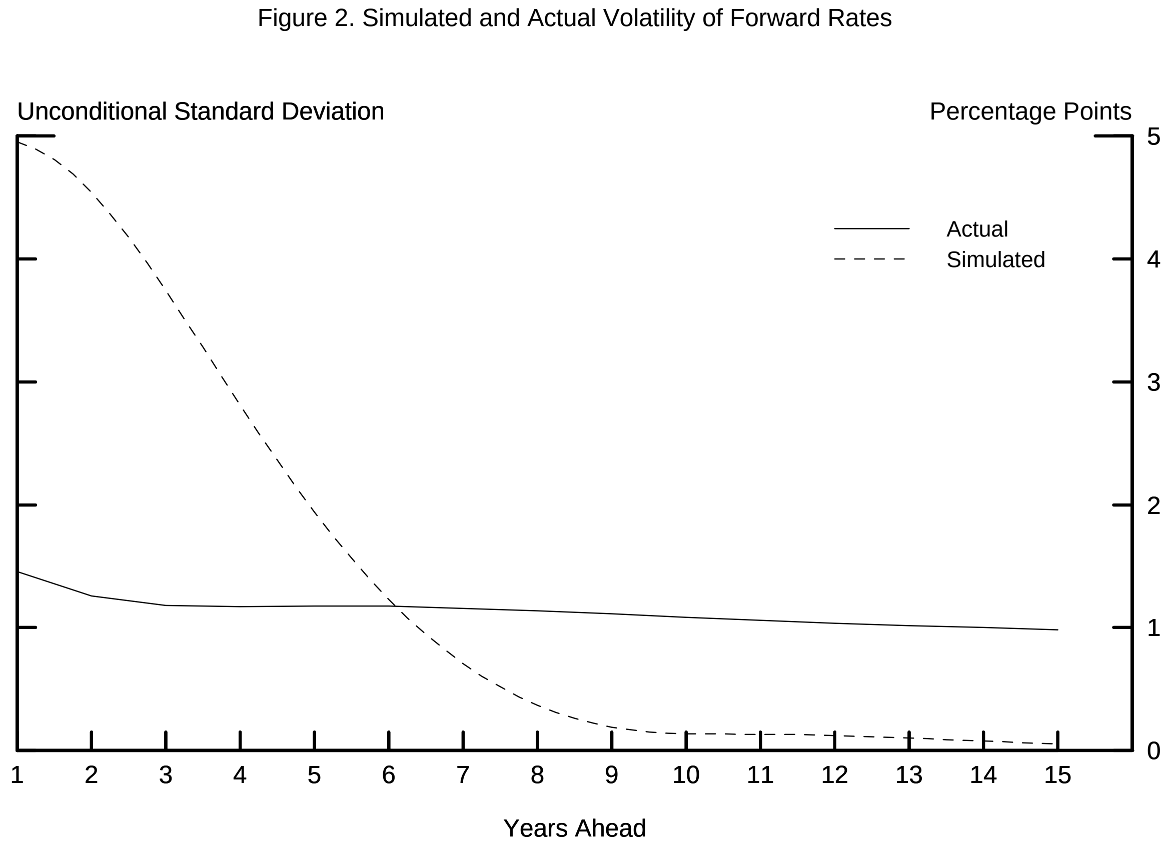

Figure 3: Response of Forward Rates to Macroeconomic Surprises

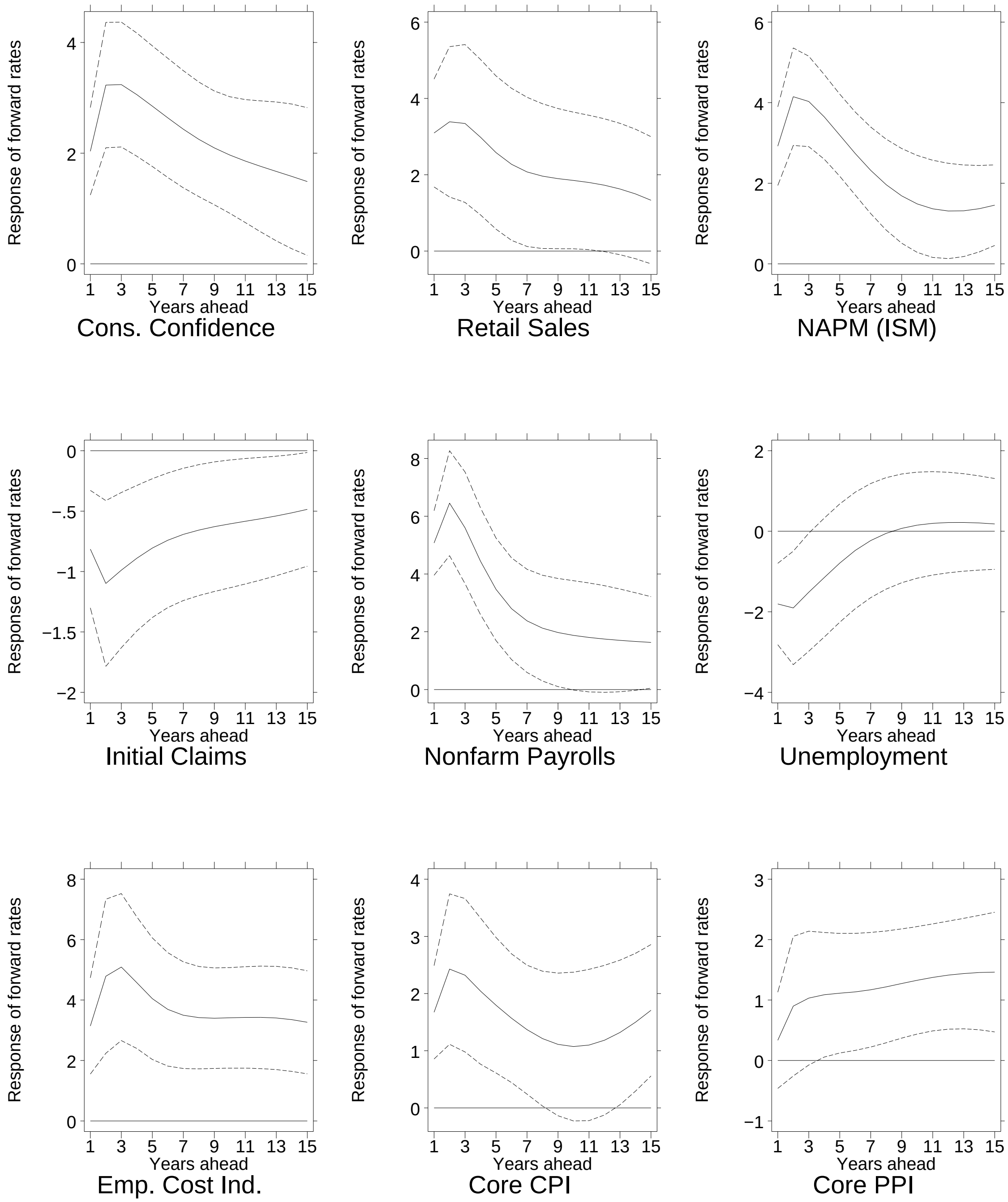

Figure 4: Response of Forward Rates to Monetary Policy Surprises

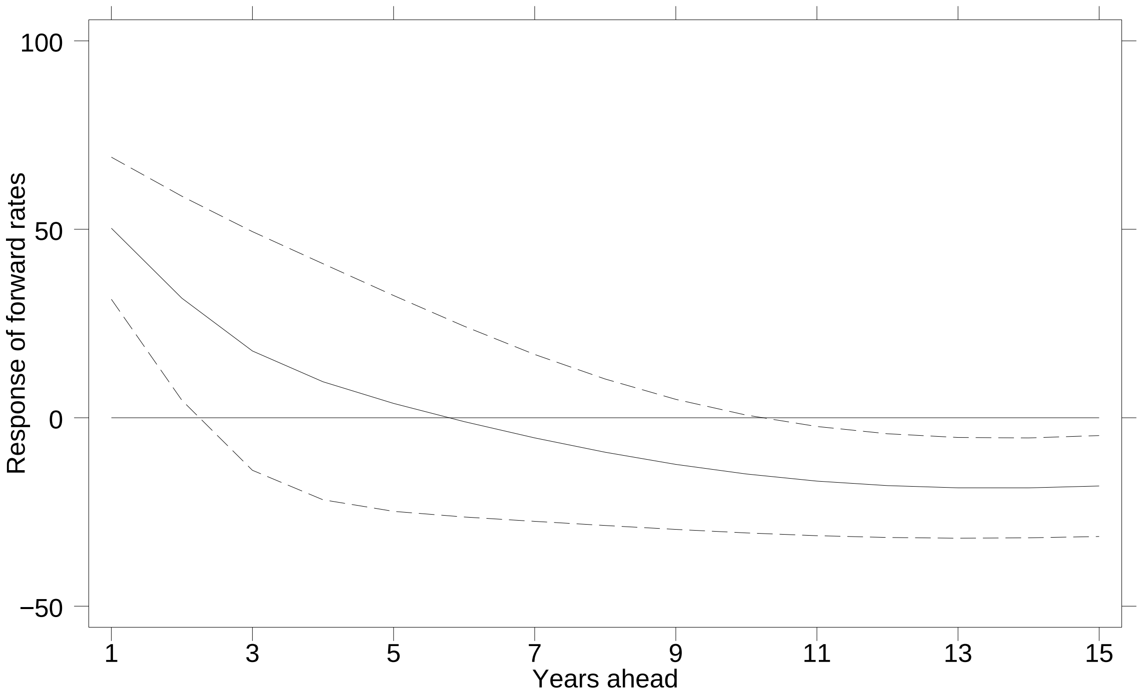

Figure 5: Ten-year-ahead Forward Rate and Monetary Policy Surprises

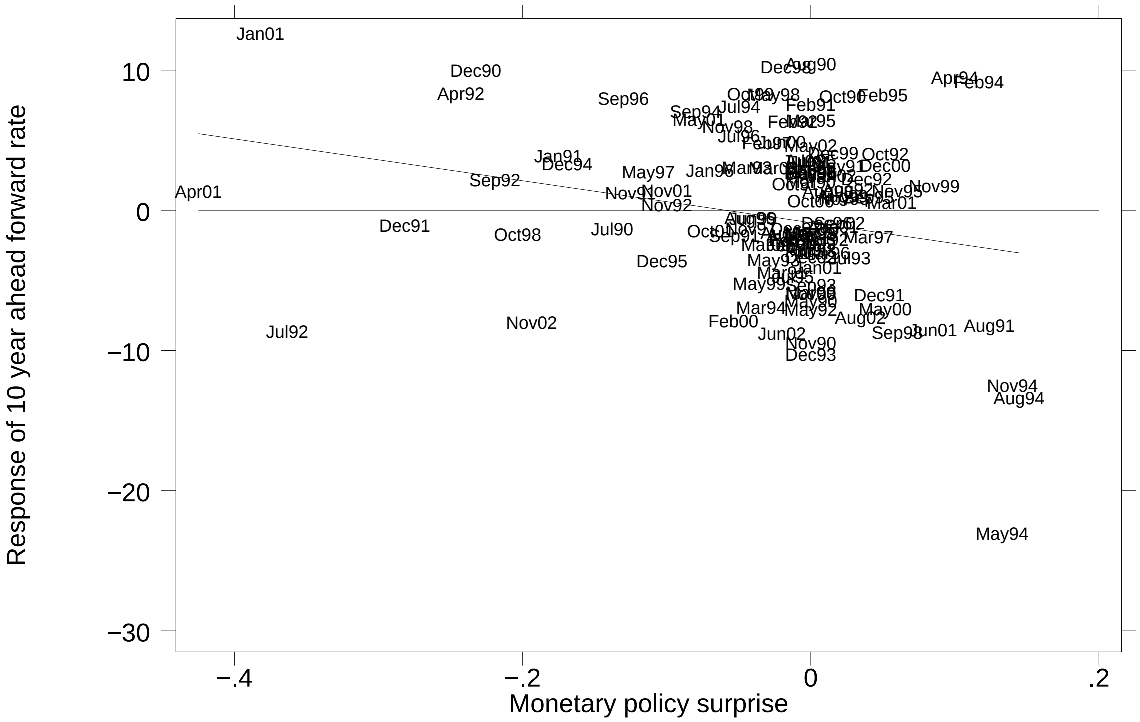

Figure 6: Interest Rate Impulse Responses for Models with Persistent Shocks

CGG Model

Rudebusch Model

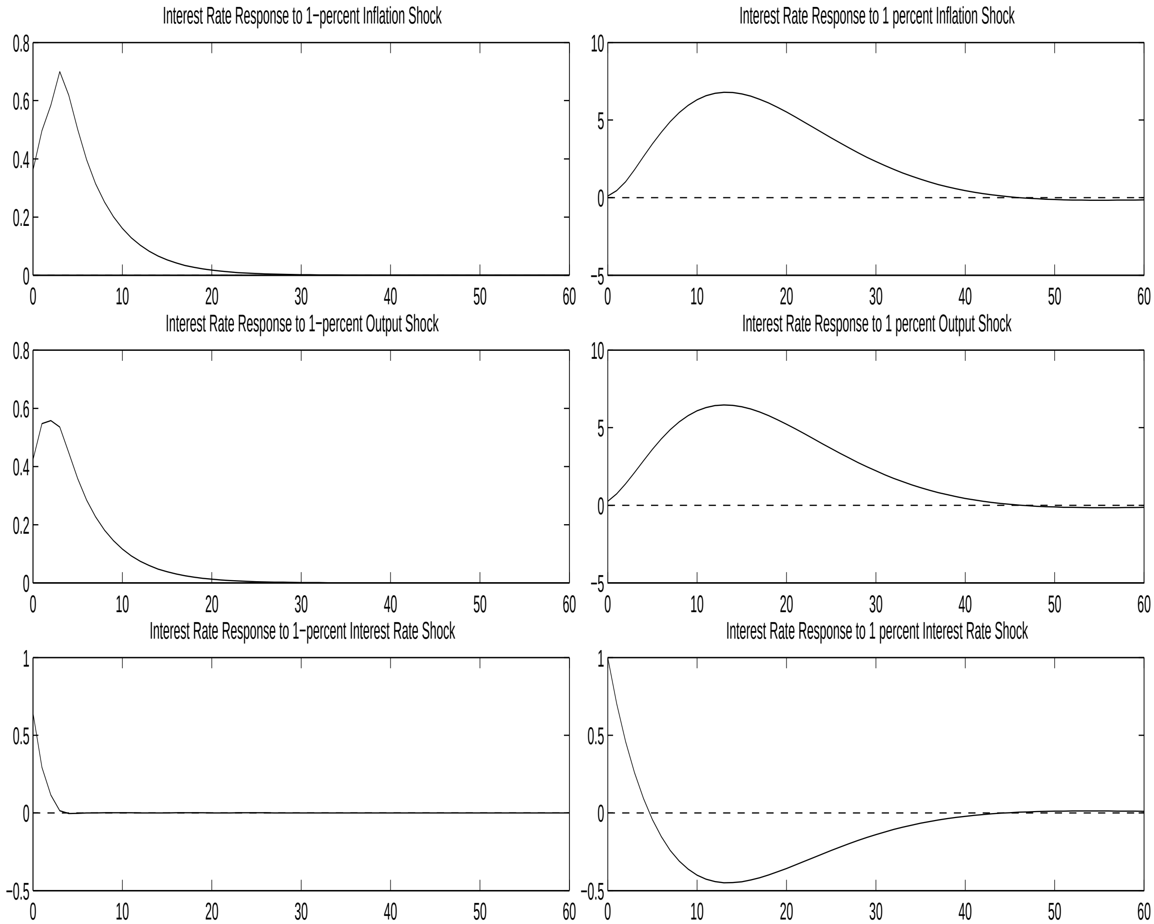

Figure 7: Interest Rate Impulse Responses for Models with Time-Varying π*

(Rudebusch Model)

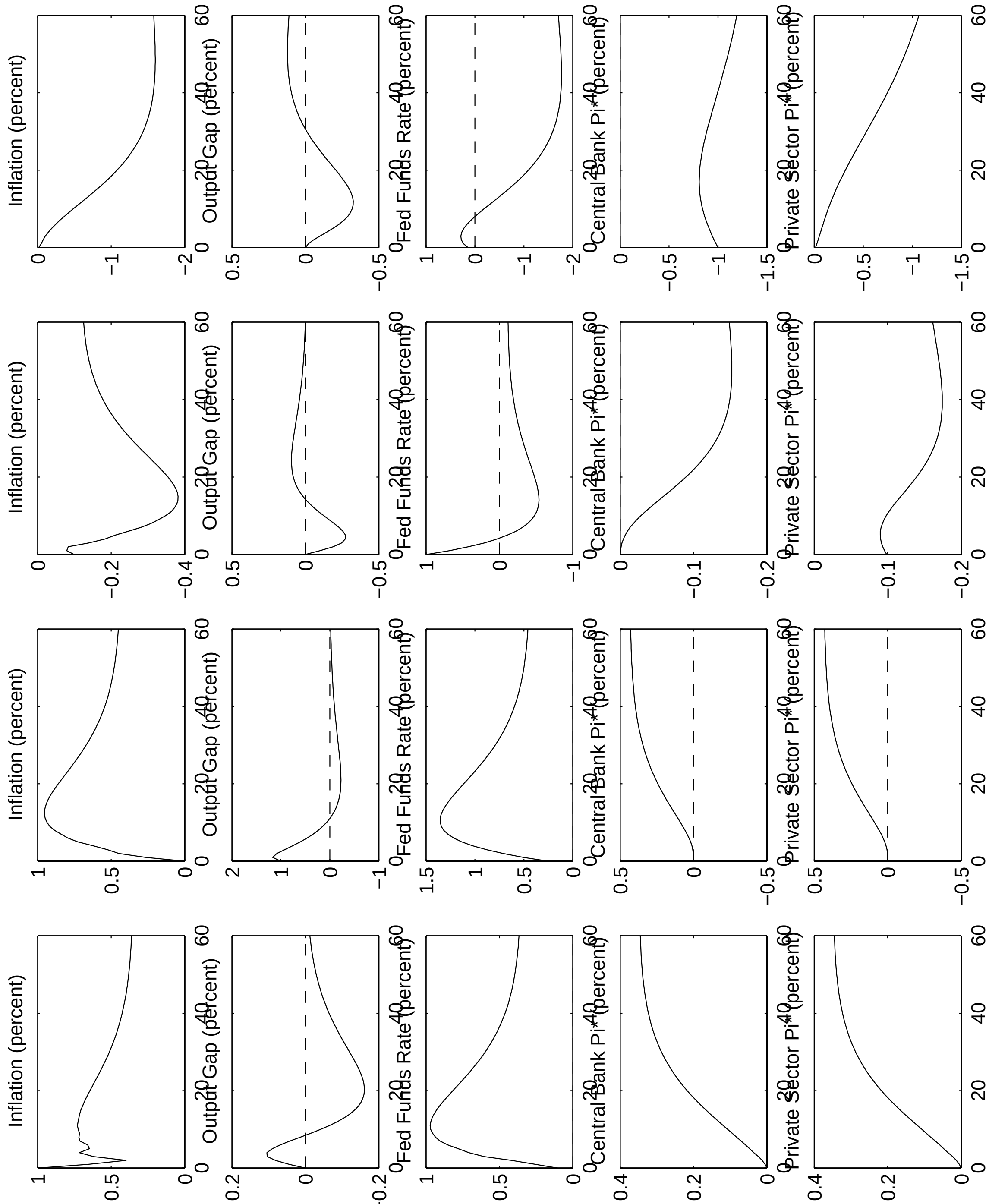

Figure 7 (cont.): Interest Rate Impulse Responses for Models with Time-Varying π*

(CGG Model with Persistent Shocks)