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

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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 inconsistent with the assumption of many macroeconomic models that the long-run properties of the economy are time-invariant and perfectly known by all economic agents. Under those conditions, 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. 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. We present an alternative model in which agents' perceptions of long-run inflation are not completely anchored, which fits all of our empirical results.

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 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 many 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 sharply with these predictions. In particular, we demonstrate that long-term forward rates move significantly in response to the unexpected components of monetary policy decisions and a number of macroeconomic data releases. We refer to this behavior as the *excess sensitivity* of long-term interest rates.

The paper then turns to potential explanations for this behavior. We find that time-varying risk 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 risk premia. 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 United Kingdom, 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

Many of the models commonly used in the macroeconomics literature 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: a pure "New Keynesian" model (taken from Clarida, Gali, and Gertler (2000) and depicted by the solid lines) and a modification of that model that allows for a significant fraction of “backward-looking” or “rule of thumb” agents (taken from Rudebusch (2001) and depicted by the dashed lines). These two models can be summarized by the following equations:

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

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

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.

The two models considered differ in the extent of their forward-looking behavior. In the pure New Keynesian model, we assume that agents are completely forward-looking, or μ=1, and we take the parameter values for the equations from Clarida, Gali, and Gertler (2000). However, much smaller values of μ (around 0.3) have been estimated and advocated by Fuhrer (1997), Roberts (1997), Rudebusch (2001), and Estrella and Fuhrer (2002) to match the degree of persistence in U.S. data. Thus, in the second model considered, we set μ=0.3 and take parameter values from Rudebusch (2001).[2]

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

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

[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.

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 the pure New Keynesian (CGG) model, the effect of the macroeconomic and monetary policy shocks on the short-term interest rate dies out very quickly, generally within a year. The interest rate displays much more persistence in the partially-backward-looking (Rudebusch) model. But even in that model, the short-term interest rate essentially return to their steady-state level well within ten years of each shock. 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 relatively short time horizon. As a result, expectations of short-term interest rates at longer horizons should be well anchored. This section investigates whether this prediction is consistent with the behavior of the term structure of interest rates.

[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.

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 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 Long-term Interest 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 risk premium (often called a term premium). If the risk 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 risk

[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.

premia are constant.[5] The predicted 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 risk premia on those instruments. Indeed, there is no reason to expect risk 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 risk 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 stochastically time-varying risk premium to the model. In particular, we demonstrate that the excess volatility of long-term forward

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[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).
[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, 1994).

rates in part arises from their systematic responses to surprises in a variety of macroeconomic data 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 the surprise component of macroeconomic data releases. We have collected data on the released values of 39 different macroeconomic statistics going as far back as 1990. 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.

In the analysis that follows, we regress daily changes in the one-year forward rate over a range of horizons 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 response to a one-standard-error surprise in the given data release. Our sample period runs from January 1990 through December 2002.

[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).

We include in the regression all of the variables that have a significant effect on the spot one-year Treasury yield (i.e., the one-year forward rate ending one year ahead).[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 ten 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, and 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.

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 horizons ending from one to 15 years ahead, together with 95% confidence bands around that estimate.[11] The

[10] 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 are significant at the 1% level. We also included the core PPI in this set of variables, 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.

[11] The confidence bands do not widen at long horizons because these regressions measure *revisions* to expectations, which have been fairly systematic over the sample. The confidence bands do not measure

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 the U.S. monetary policy reaction function (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.

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uncertainty about the *level* of the short-term interest rate that will be realized over those horizons, which would generally increase with the horizon.

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 FOMC policy decisions themselves.

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).[12] 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:[13]

$$i_t - E_{t-1} i_t = (D/(D-d)) \cdot \Delta f\!f1_t \tag{3.2}$$

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 $\Delta f\!f1$ is the change in the rate on the current month's federal funds futures contract.

We compute monetary policy shocks for all FOMC meetings and intermeeting policy actions since 1990. One small complication arises in the timing of the shocks: since

[12] 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.

[13] 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.

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.[14]

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:[15]

$$\Delta 10yrfwd = \underset{(0.597)}{-0.880} - \underset{(0.079)}{0.149}*surprise, \qquad R^2 = 0.06 \qquad N = 114$$

[14] We take into account some exceptions to this timing convention, including those noted in Kuttner (2001).
[15] 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.

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:

$$\underset{}{\Delta 10yrfwd} = \underset{(0.739)}{-0.748} - \underset{(0.101)}{0.202}*surprise. \qquad R^2 = 0.10 \qquad N = 76$$

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—that long-term interest rates tend to move in the same direction as policy actions. 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 useful measure for investigating excess sensitivity.[16] 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.

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 (see Figure 1). Moreover, the fact

[16] 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.

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 these movements. However, before turning to possible explanations for our empirical findings, 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.[17] By relying on STRIPS, we can obtain a purely market-based reading of forward rates that does not require any smoothing.[18]

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. 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 lack of data. The sample here begins in 1994, when reliable STRIPS data are first available to us.

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

[18] 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.

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, ten 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:

$$\Delta 10yrfwd = \underset{(0.713)}{-0.775} - \underset{(0.082)}{0.301}*surprise \qquad R^2 = 0.18 \qquad N = 73.$$

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 to the measurement of those rates. 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:

$$i^* = r^* + \pi^* \tag{4.1}$$

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 indicates 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. More Persistent 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 much more quickly than the horizon required to support this explanation.

In section 2, we presented interest rate impulse response functions from two baseline macroeconomic models. 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 ten 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 (again ,beyond 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 interest rates and for long-term interest rates in the U.K. In fact, as we show in sections 5 and 6, 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 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 several 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, indicating that the findings are not driven by a risk premium associated with uncertainty about real interest rates. Furthermore, we show in section 6 that the excess sensitivity of long-term rates in the U.K. disappeared once the Bank of England gained independence, suggesting that it had been driven primarily by changes in investors' perceptions about long-run inflation. In order to explain these 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^* is inherently difficult. Nevertheless, it seems likely that if inflation expectations at long horizons are perfectly anchored, as in the two models considered above, then the risk premium associated with them would be relatively small and unresponsive to current shocks.[19] To the extent that long-run inflation expectations are not perfectly anchored, as we consider next, both inflation and the inflation risk premium might respond together to the various shocks considered. The exact breakdown between mean inflation and inflation risk is of secondary concern for the main point of our paper—that it is concerns about future inflation that account for the excess sensitivity of long-term rates. For simplicity, we focus on changes in the mean long-run inflation

[19] Indeed, in those models the entire distribution of inflation at long enough horizons is unaffected by current shocks to the model. It also seems difficult to construct a model in which inflation risk could explain the term structure evidence without any changes in mean expected inflation. Such a model would require that inflation risk depend on the *sign* of the shock and not just on its absolute *magnitude*. For example, one would have to argue that uncertainty about inflation increases after a positive CPI surprise and decreases after a negative CPI surprise.

rather than inflation risk. This assumption is also supported by Ang and Bekaert (2003), who find that movements in the mean of long-run inflation dominate movements in the inflation risk premium in an affine term structure model fitted to U.S. data.[20]

*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.[21]

We can demonstrate this by augmenting the baseline models from section 2 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 those citizens.[22] 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, as follows:

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

[20] Ang and Bekaert (2003) estimate an affine term structure model with regime switching that separates expected long-run inflation from the inflation risk premium. Under the assumption that changes in inflation risk at very short (one-quarter-ahead) horizons are negligible, they 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.
[21] Changes in the long-run inflation rate might also affect the long-run level of real interest rates by influencing the steady-state level of capital, for example by creating tax distortions. Our point, however, is that changes in π^* are a necessary component of the explanation.
[22] For example, it could be 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 could be more substantial.

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.[23]

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 Kozicki and Tinsley (2001a), Ellingsen and Soderstrom (2001), and Erceg and Levin (2003). 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. Private agents update their estimate of the central bank's inflation target, denoted $\hat{\pi}_t^*$, by Kalman filtering.[24] In particular, agents observe the deviation of the interest rate from their expectation, $i_t - \hat{i}_t$, where $\hat{i}_t$ is

[23] This has some similarities to the idea of "opportunistic disinflation" described in Orphanides and Wilcox (1996).

[24] This procedure is optimal under the assumptions of normally distributed shocks and a normally distributed prior for the inflation target. For other shock distributions, the Kalman filter is the optimal linear inference procedure.

determined from their knowledge of equation (4.6), and they revise $\hat{\pi}_t^*$ by an amount determined by the Kalman gain parameter κ.

To implement this model, we maintain the parameter values from section 2, but now require values for the parameters θ and κ. We choose values of these parameters to roughly calibrate our impulse response functions to match the estimated responsiveness of long-term forward rates in our data. One could alternatively estimate all the parameters of the model jointly, but we leave that to future research; the exercise here is intended to illustrate the ability of the model to account for our basic term structure findings.[25] It turns out that we require relatively small values for θ (the extent to which the central bank's inflation target responds to current inflation) to match the term structure evidence. In particular, we set θ equal to 0.02 and κ equal to 0.1.

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. The rows of the figure show 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 one-percent innovation to each of the shocks. The columns are organized by the source of the shock.

The qualitative features of our empirical findings are reproduced very nicely. For example, after an inflation shock (the first column), 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 (the second column).

[25] Moreover, re-estimating all the parameters would limit the comparability of the results to those shown earlier.

For the federal funds rate shock (the third column), 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 (2003)) 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. 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 equal to 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 that the central bank will not drive inflation after a shock all the way back to the previous long-run target π^*. For simplicity, we do not pursue these modifications here.

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 ten-year CPI inflation forecast in the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters has fallen from 4 percent in the fourth quarter of 1991 (the first time the long-run forecast question was asked) to a little under 2½ percent by the end of 2002. This decline of about 1½ percentage points compares with a fall of about 2½ percentage points in ten-year nominal forward interest rates over the same period.

Overall, the hypothesis that the markets' long-term inflation expectations have varied systematically in response to macroeconomic and monetary policy surprises provides a plausible explanation of the behavior of the term structure. We next turn to more direct evidence based on indexed debt.

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 maturity 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 about 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 recompute 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.

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. Those responses are more often associated with its inflation compensation (the difference between the nominal and real rates) than with its real component. Indeed, the response of the long-term real forward rate is only marginally significant for two variables, and in both of those cases the significance is driven by a single influential observation. Inflation compensation instead responds significantly to four of the seven variables. Moreover, 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.[26]

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

[26] 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.

inflation. We investigate this question by looking at the response of forward rates in the United Kingdom 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.

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.[27] 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

[27] Similarly, Joyce and Read (1999) find that nominal forward rates five and ten years ahead respond to RPI data releases in a sample that ends before the Bank of England was granted operational independence.

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 in response to these macroeconomic and monetary policy surprises.

This conclusion has potentially important implications for the macroeconomic models themselves. Not only would those models have difficulty capturing the long-run behavior of the economy, but any misspecification of those long-run properties could alter the short-run structural behavior of the models as well. In particular, 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 macroeconomic and monetary policy surprises, the Federal Reserve has achieved remarkable economic performance over our sample period, with inflation expectations falling to very low levels. 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.

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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	-1.891	0.815 **	-0.956	0.739	-0.033	0.708	-0.92	0.79
Policy Surprise	0.228	0.148	-0.163	0.124	0.049	0.045	-0.211	0.096 **
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

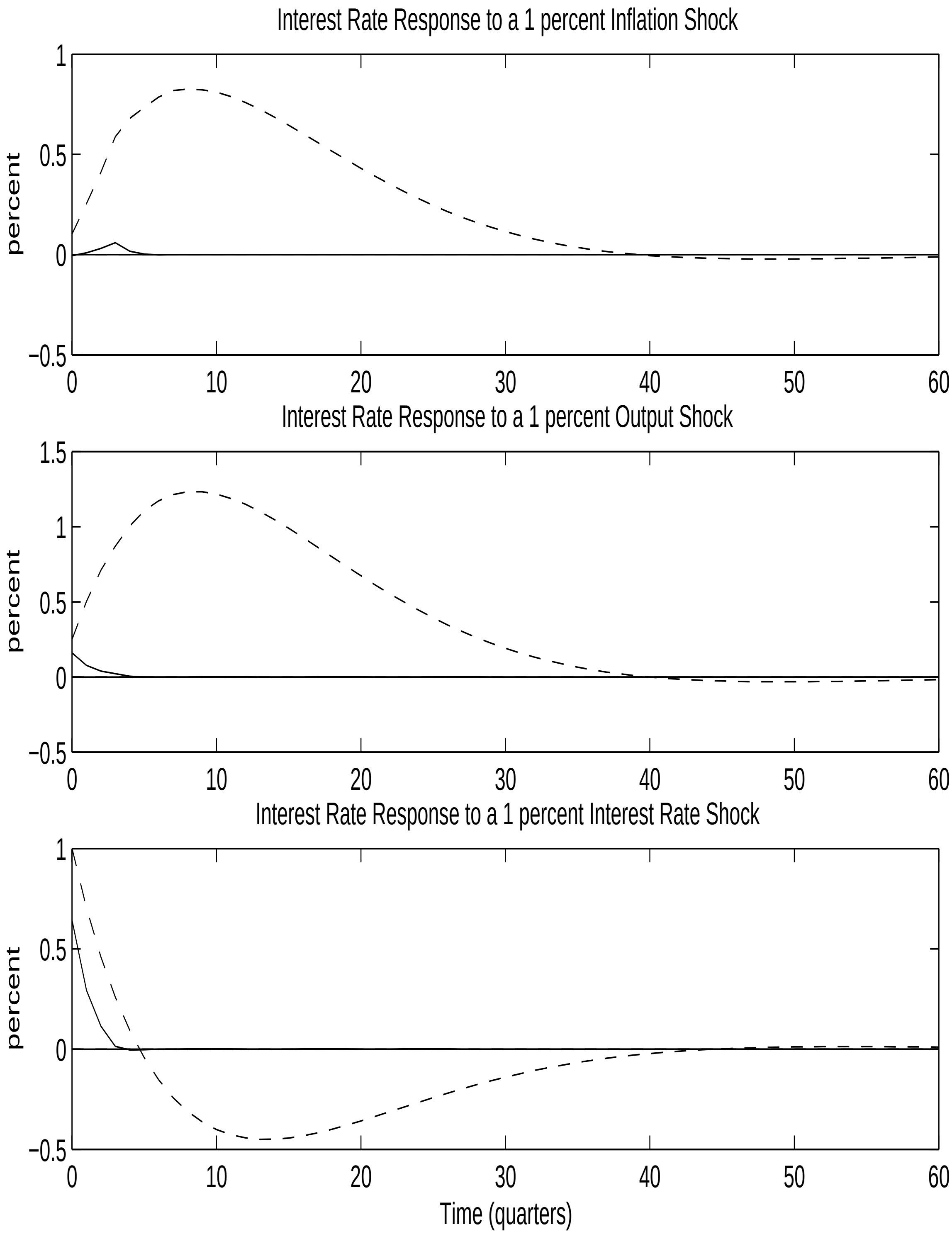

Figure 2: Simulated and Actual Volatility of Forward Rates

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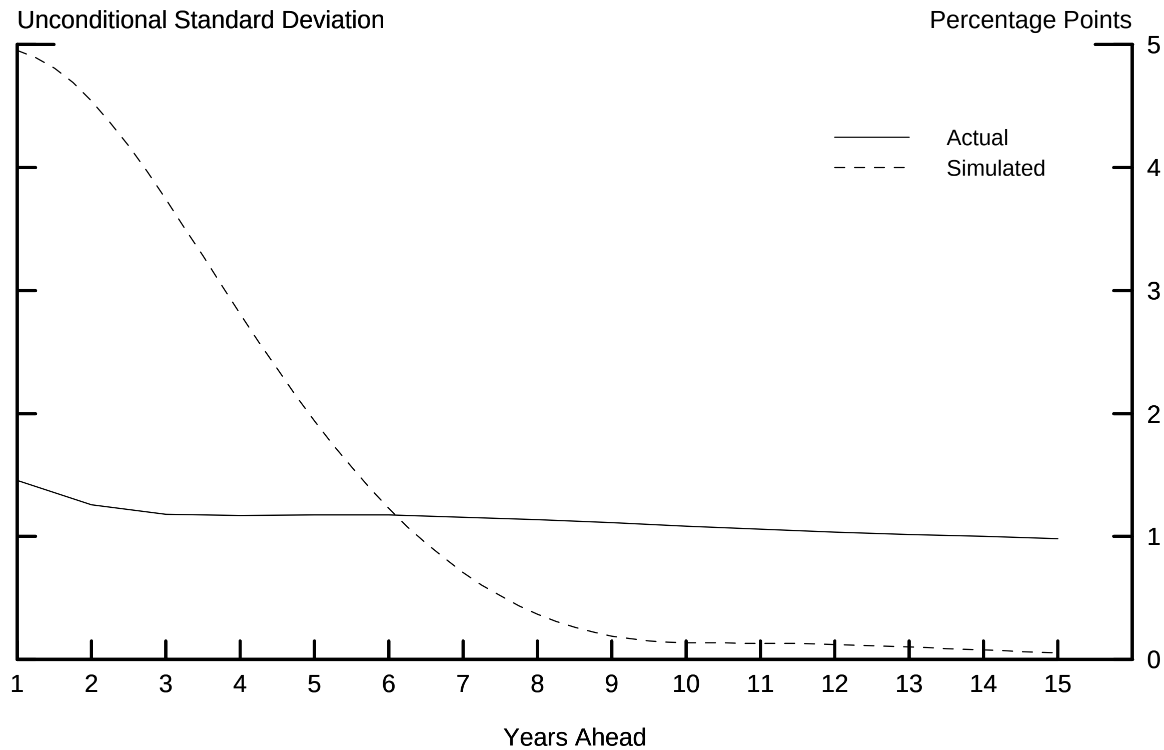

Figure 3: Response of Forward Rates to Macroeconomic Surprises

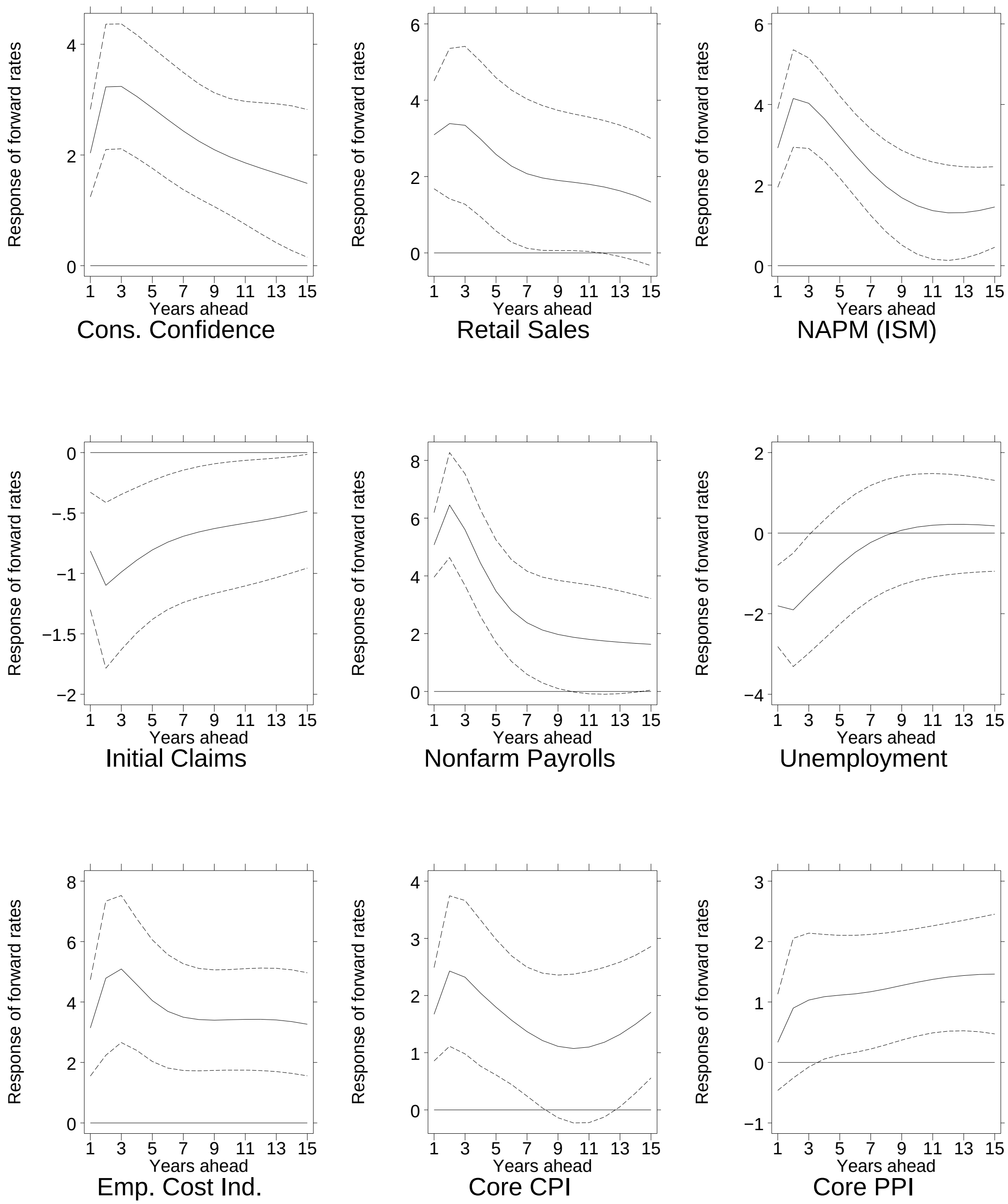

Figure 4: Response of Forward Rates to Monetary Policy Surprises

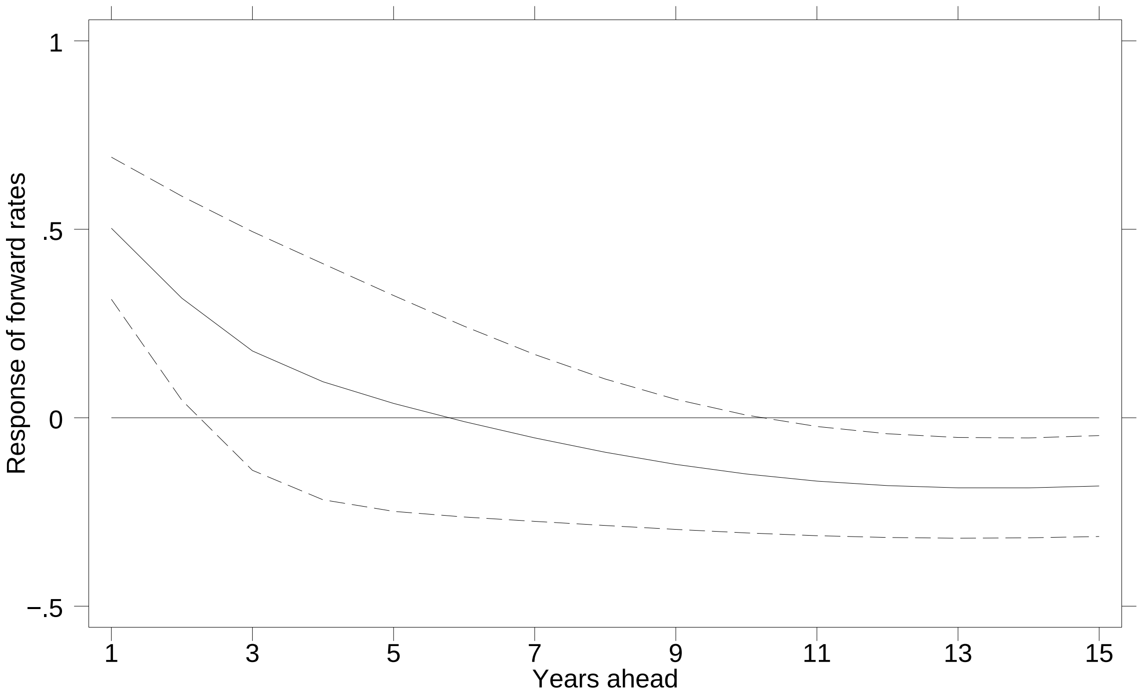

Figure 5: Ten-year-ahead Forward Rate and Monetary Policy Surprises

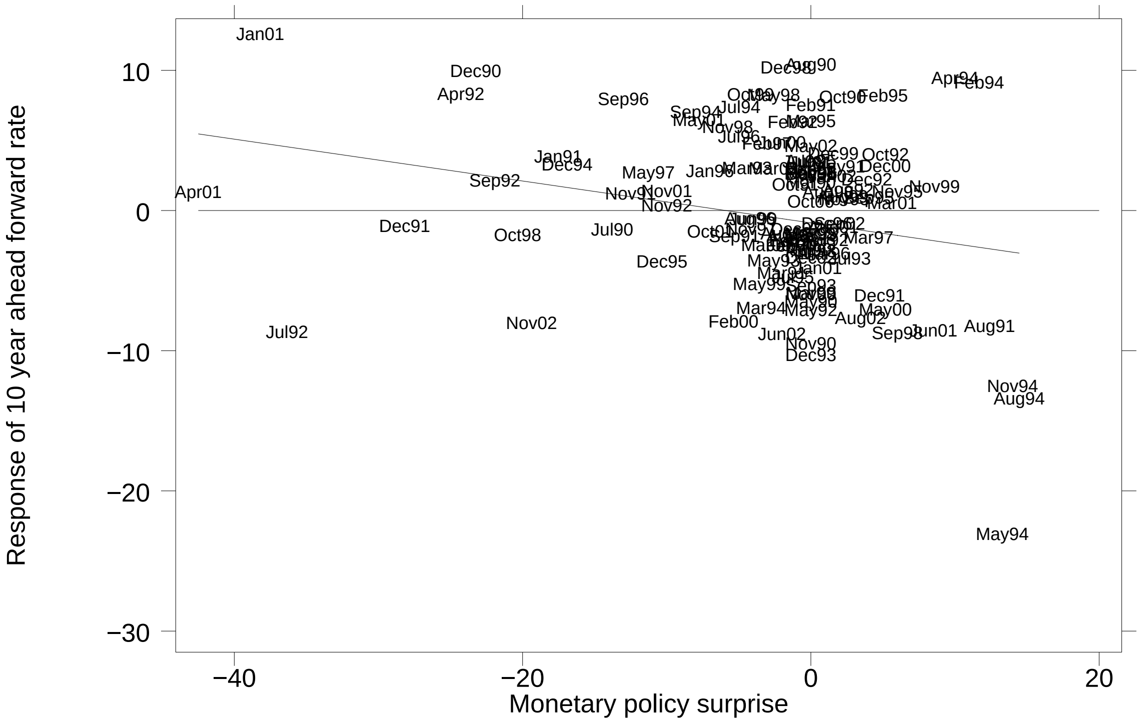

Figure 6: Interest Rate Impulse Responses for Models with Persistent Shocks

CGG Model | Rudebusch Model

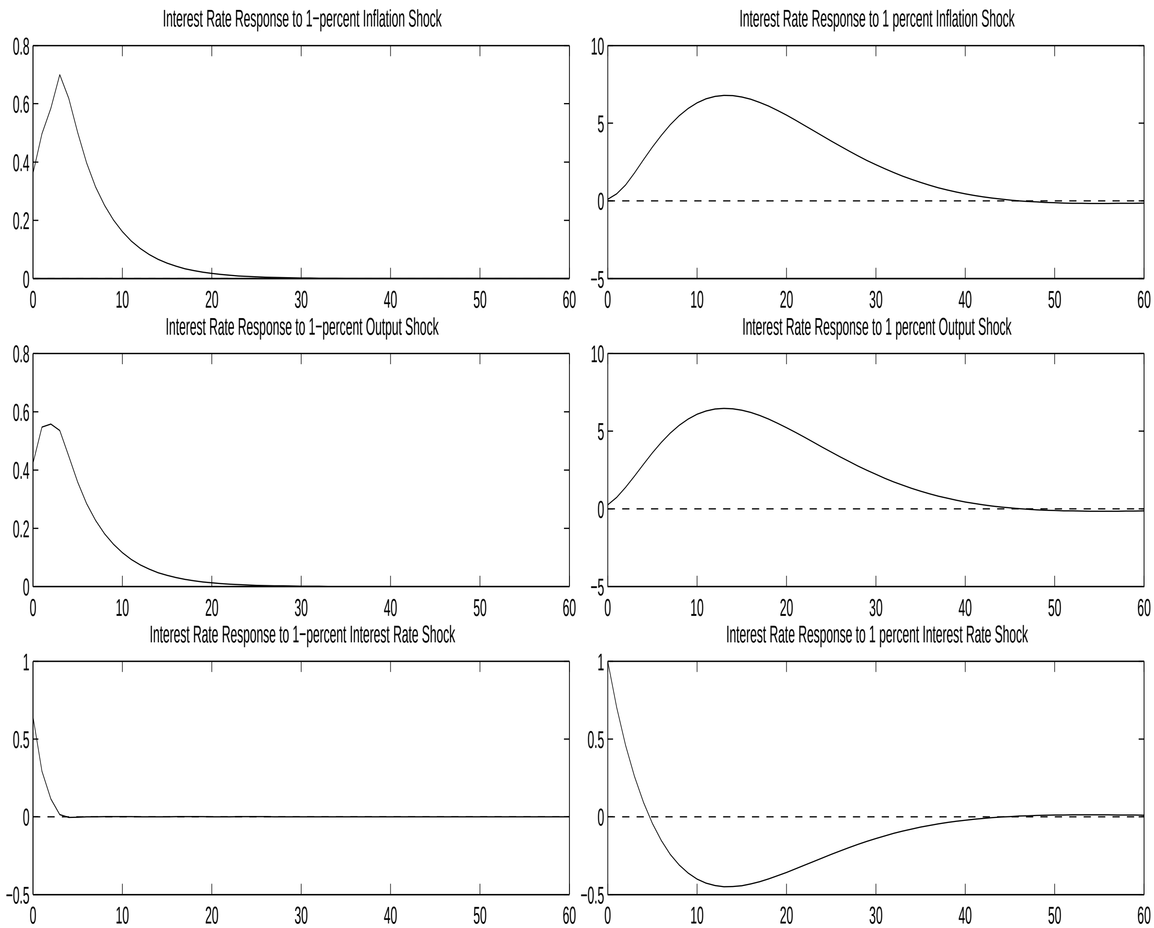

Figure 7: Interest Rate Impulse Responses for Models with Time-Varying π*

(Rudebusch Model)

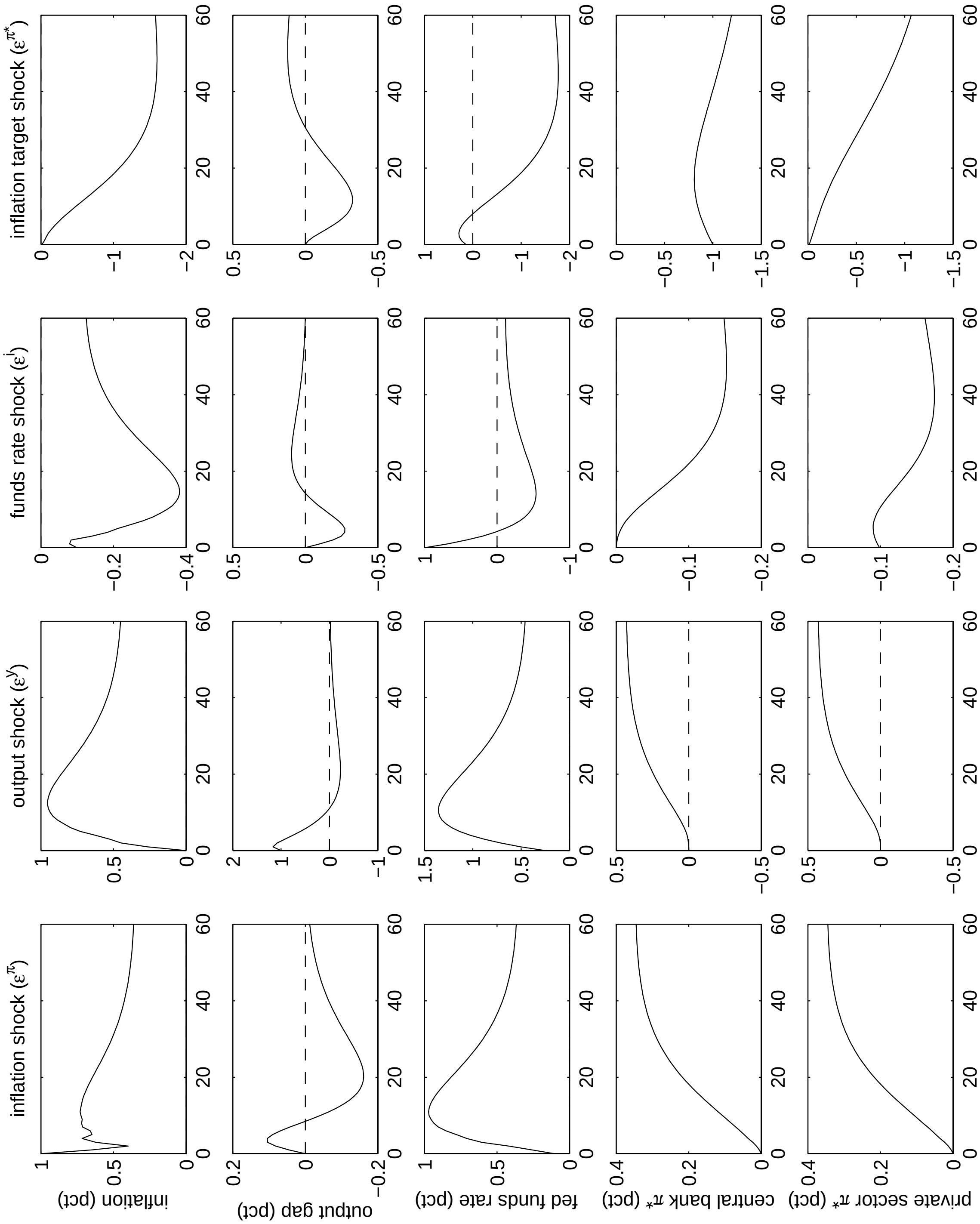

Figure 7 (cont.): Interest Rate Impulse Responses for Models with Time-Varying π*

(CGG Model with Persistent Shocks)