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James D. Hamilton

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ABSTRACT

This paper offers an explication of the hump-shaped response of real economic activity to changes in monetary policy, focusing on the particular channel operating through new home sales. I suggest that the conventional notion of a monetary policy shock as a surprise change in the fed funds rate is misspecified. The primary news for market participants is not what the Fed just did, but is instead new information about what the Fed is going to do in the near future. Revisions in these anticipations show up instantaneously in long-term mortgage rates. Although mortgage rates respond well before the Fed actually changes its target rate, home sales do not respond until much later. The paper attributes this delay to cross-sectional heterogeneity in search times. This framework offers a description of the lags in the effects of monetary policy that is both more detailed, allowing us in principle to measure the consequences at the daily frequency, and more believable than traditional measures.

James D. Hamilton
Department of Economics, 0508
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0508
and NBER
jhamilton@ucsd.edu

1 Introduction.

How do we measure the effects of monetary policy on the economy? One popular approach (e.g., Christiano, Eichenbaum, and Evans, 1999) is based on a structural VAR. Let $\mathbf{y}_m$ denote a vector of variables observed for month m of which the average fed funds rate over the month, r_m, is one element. Suppose we formed a linear forecast of $\mathbf{y}_{m+s}$ based on lagged values of $\mathbf{y}$ (denoted Ω_{m-1}) and some subset of the current values of $\mathbf{y}$ (denoted Λ_m). How would news about the value of r_m, denoted u_m, cause us to revise our expectation of $\mathbf{y}_{m+s}$? The standard impulse-response function is simply a graph of the answer to this question[1] :

$$\frac{\partial \hat{E}(\mathbf{y}_{m+s}|u_m, \Lambda_m, \Omega_{m-1})}{\partial u_m}. \tag{1}$$

Much of the discussion in the literature concerns which elements of $\mathbf{y}_m$ to include in the contemporaneous information set Λ_m. However, this choice often proves of limited consequence. Figure 1 displays impulse-response functions for a fairly standard VAR including industrial production, the CPI, commodity prices, the fed funds rate, and M2.[2] One sees the same broad hump-shaped response, with an increase in the fed funds rate being followed after a substantial delay by a slowdown in industrial production, regardless of the specification of Λ_m.

Although the choice of Λ_m makes little difference for the answer to this forecasting

[1] Here $\Omega_{m-1} = \{\mathbf{y}_{m-1}, \mathbf{y}_{m-2}, ...\}$ and $u_m = r_m - \hat{E}(r_m|\Lambda_m, \Omega_{m-1})$. See for example Hamilton (1994, eqs. [11.4.19] and [11.6.16]).

[2] The commodity price index is the Reuters/CRB index from http://www.crbtrader.com/crbindex/. All other series were obtained from the St. Louis FRED database. The first four series were converted to 100 times the year-over-year logarithmic change. The sample period is 1961:01 to 2008:03, and 12 lags were used.

question, the specification of the lagged information set Ω_{m-1} is quite significant, as stressed by Rudebusch (1998) and Brissimis and Magginas (2006). The top panel of Figure 2 plots the errors u_m associated with a monthly VAR (in which the fed funds rate is ordered last) between 2003:01 and 2006:06. The second panel plots the difference between r_m and the forecast implied by the 1-month fed funds futures contract on the last day of month $m-1$. Over this period, changes in the fed funds rate that would be characterized by the VAR as monetary policy shocks were in fact almost perfectly anticipated by market participants.

This is not to say that there were no surprises in monetary policy over this period. However, any surprises were not about what the Fed just did, but instead reflected new information about what the Fed was going to do in the future. The bottom panel plots revisions during each month in the anticipation of what the fed funds rate was going to be 2 months after the indicated month. For example, what the VAR classifies as a surprisingly high fed funds rate in July 2004 actually showed up as news to markets in a much more modest adjustment in the July fed funds contract price between April 30 and May 31. This paper presents evidence that, for purposes of determining long-term mortgage rates or new home sales, only unanticipated monetary policy changes matter, that is, it is the bottom panels rather than the top panel in Figure 2 that will affect the economy

Before proposing my alternative to the forecasting question posed by (1), let me clarify what it is that I believe we're trying to estimate. The primary input the Fed needs from empirical researchers is an answer to questions like the following:

> We're trying to decide between a funds rate of 5 or 5.25. How would the

predicted path for $\mathbf{y}_{m+s}$ be different under the two choices?

This question is potentially related to the impulse-response function in (1), in that both represent questions about a conditional forecast. However, interpreting an object like (1) as telling us the answer to the policy question of interest faces two challenges. First, for purposes of the policy question, it is clear that the information set we'd like to use is all the information available to the Fed prior to the decision. That suggests that the bottom panels of Figure 2 are more promising measures than the top, and indeed ideally we would want to use forecasts from the day before rather than a month before the Fed's decision.

The second challenge is whether the conditions that caused surprise movements in r_m in our sample are comparable to those that would govern the outcome of the policy question currently contemplated. For example, if historically the Fed raised r_m in response to new inflation fears that month, to what extent is what we see happen to $\mathbf{y}_{m+s}$ a result of the inflation itself, and to what extent does it result from the choice made by the Fed?

A number of papers have sought to resolve these problems by looking at the change in expectations of the fed funds rate on the day of a Fed policy change or announcement itself, supposing that on such days, the answer to the forecasting question might isolate the effect of policy alone. Such studies include Kuttner (2001), Cochrane and Piazzesi (2002), Faust, Swanson and Wright (2004), Gürkaynak, Sack, and Swanson (2005a,b), and Andersson, Dillén, and Sillin (2006), among others. All of the above papers simply assume that the conditional forecasting question has a different answer on these days relative to others. To my knowledge, mine is the first paper to test this assumption, and I find that over the period

1988-2006, it appears not to be the case. That finding opens up a vastly bigger and richer data set than previous researchers have used for purposes of calculating how revisions of forecasts of the fed funds rate are associated with revisions of the forecasts of other macro variables of interest.

I also differ from most previous studies in making primary use of daily innovations in the one- and two-month-ahead futures contracts rather than the spot-month contract. As suggested in the second and third panels of Figure 2, the most important news about the Fed in recent years has been information about what it is going to do rather than information about what it just did. Poole and Rasche (2000), Gürkaynak (2005), and Gürkaynak, Sack, and Swanson (2007) looked at the comovements between near-month contracts (rather than spot-month contracts) and asset prices on policy days. But the current paper is again I believe the first to try to link changes in these contracts directly to subsequent changes in a measure of real economic activity.

The way in which I do so is also methodologically novel. I propose a new method for combining data observed at different frequencies based on parametric restrictions inspired by the observed cross-sectional heterogeneity in search times.

The plan of the paper is as follows. Section 2 reviews evidence on the time-series properties of daily changes in near-term fed funds futures prices, and concludes that these changes primarily result from daily changes in a rational anticipation of what the Fed is going to do next. Section 3 documents that weekly mortgage rates follow a near-martingale, and relates its innovations to daily changes in fed funds futures. I document that this relation appears to be invariant with respect to which day of the week one uses, whether one uses only those changes associated with policy announcement days, days of particular macroeconomic news releases, or the level of time aggregation up to a month. Section 4 investigates the forecasting relation between interest rates and the level of new home sales, documenting that there is a very long, sustained lag. Some of the sales for a given month depend on mortgage rate changes that occurred during the previous month, while sales of other homes within that same month appear to be responding to mortgage rates up to six months earlier. The paper attributes this lag in part to heterogeneity across households. The mean lag of the time-series relation turns out to match closely the mean lag of the cross-sectional distribution across different households in the time spent searching before buying a home.

Taken together, the evidence supports the following interpretation of the way in which monetary policy affects the economy. Current mortgage rates reflect a rational anticipation of everything the Fed may do in the future. If the Fed wants to change mortgage rates, it has to do something other than what the market expected. Any new information about what the Fed is going to do shows up essentially instantly in mortgage rates, but due to heterogeneity across households in information–processing and search times, shows up only gradually over time in new home sales. The biggest effect on home sales is observed 15 weeks after the change in policy is first perceived by futures markets.

2 Anticipations of the fed funds rate.

2.1 Fed funds futures data.

The fed funds rate for month m, denoted r_m, is typically measured as the average value of the effective fed funds rate over all the days of that month. Since October 1988, it has been possible on any business day to buy or sell through the Chicago Board of Trade a futures contract whose payoff depends on what the value of r_m turns out to be. A contract on day d for the current month specifies a futures price or interest rate, denoted $F_1(d)$, such that if the current month's fed funds rate (denoted $r_{m^*(d)}$) turns out to be less than $F_1(d)$, the seller of the contract will have to compensate the buyer an amount that depends on the difference $F_1(d) - r_{m^*(d)}$. If $r_{m^*(d)} > F_1(d)$, the buyer will pay the seller. One can also buy a contract for the following month, whose implied interest rate is denoted $F_2(d)$. For example, one could purchase on $d =$ May 22, 2006 a contract specifying $F_2(d) = 503$ basis points (a 5.03% annual interest rate). The actual interest rate for June turned out to be $r_{1+m^*(d)} = 500.5$ basis points, so the buyer of that one-month-ahead contract made a slight profit. One could also purchase a 2-month-ahead contract at rate $F_3(d)$, which if purchased on May 22 would be a bet about the July value for r_m. Longer-term contracts can also be traded, though many a bit thinly in the early part of the sample, and this study will focus on only the very near-term contracts.

The basic data used in this study are the daily changes (in basis points) of each day's settlement futures prices over the period October 3, 1988 to June 30, 2006.[3] Let $f_1(d)$

[3] Data were purchased from the Chicago Board of Trade.

denote the change on day d for the current month's contract:

$$f_1(d) = \begin{cases} F_1(d) - F_1(d-1) & \text{if } m^*(d) = m^*(d-1) \\ F_1(d) - F_2(d-1) & \text{otherwise} \end{cases}.$$

Thus a positive value for $f_1(d)$ might be taken as a signal that investors received some information during day d leading them to anticipate a higher value for $r_{m^*(d)}$ than they had previously expected. Likewise let $f_2(d)$ denote $F_2(d) - F_2(d-1)$ for a typical day (and $f_2(d) = F_2(d) - F_3(d-1)$ if d is the first day of the month) while $f_3(d) = F_3(d) - F_4(d-1)$ if d is the first day of the month and $f_3(d) = F_3(d) - F_3(d-1)$ otherwise.

Standard finance theory states that the futures prices should satisfy

$$E_d[\lambda_j(d)F_j(d)] = E_d[\lambda_j(d)r_{m^*(d)+1-j}]$$

for $E_d[]$ the expectation based on all information available at the end of day d and $\lambda_j(d)$ the pricing kernel relating day d to the first day of the next jth month. As noted by Hamilton (forthcoming), the pricing kernel $\lambda_j(d)$ is in units of a few month's interest factor, and as the time horizon becomes shorter, its mean approaches unity and variance goes to zero. For this reason, daily changes in the prices of the very near-term futures contracts might be expected to be dominated by new information about interest rates,

$$f_j(d) \simeq E_d(r_{m^*(d)+1-j}) - E_{d-1}(r_{m^*(d)+1-j}) \tag{2}$$

with the approximation exact in the special case of risk neutrality.

My forthcoming paper examined some of the empirical evidence in support of (2). Although most previous researchers such as Sack (2004) and Piazzesi and Swanson (forthcoming) have found[4] a statistically significant negative mean for $f_i(d)$, this is strongly influenced by a few big interest rate drops that caught the market by surprise. Maximum likelihood estimation of the population mean of $f_i(d)$ that allows for EGARCH and calendar-based heteroskedasticity along with a non-Normal distribution ends up implying a positive (and far from statistically significant) rather than a negative value for the mean.

My earlier analysis did find some statistically significant serial correlation in $f_i(d)$, but this seems to be of very limited economic significance. The one-day-ahead R^2 from these autoregressions is below 0.03 and the forecastability more than one day ahead is essentially zero.

Piazzesi and Swanson (forthcoming) proposed a number of interest rate spreads that seem to help predict longer-horizon monthly fed funds futures pricing errors. My analysis of daily data (Hamilton, forthcoming) found that the previous day's values for these spreads were generally of very limited use for trying to predict $f_i(d)$ for $i = 1, 2$, or 3. That paper also confirmed Piazzesi and Swanson's finding that the monthly nonfarm payroll does seem to make a statistically significant contribution for predicting $f_2(d)$ and $f_3(d)$, though the R^2 of this regression is only 2%. The results that will be reported below turn out to be unaffected by whether or not these numbers are included as conditioning variables. I also found a statistically significant coefficient on the first lag $f_i(d-1)$ in a 5-day autoregression. However,

[4] Most previous studies have looked at monthly forecast errors such as $r_m - F_2(d^\dagger(m-1))$ for $d^\dagger(m)$ the last day of month m. Since I'm using settlement prices, $F_1(d^\dagger(m)) = r_m$ and $\sum_{d \in A(m)} f_1(d)$ is identically equal to $r_m - F_2(d^\dagger(m-1))$ for $A(m)$ the set of all days that fall within month m. Thus the sample mean of $f_1(d)$ is based on exactly the same statistic (namely, the sum of all $f_1(d)$) as is the sample mean of $r_m - F_2(d^\dagger(m-1))$.

this coefficient is only 0.15, implying again a tiny R^2 and virtually zero predictability more than one day in advance.

Furthermore, as documented more fully by Gürkaynak, Sack, and Swanson (2007), among others, the near-term futures contracts offer excellent forecasts of the actual fed funds rate. For example, let $d^{\dagger}(m)$ denote the last business day of month m. For the full sample of data studied here, the forecast errors associated with one-month-ahead futures contracts $r_m - F_2(d^{\dagger}(m-1))$ have an average squared value of 128 basis points, which is only a third of the average squared change in the funds rate itself $(r_m - r_{m-1})$. The mean squared errors for two-month-ahead contracts $r_m - F_3(d^{\dagger}(m-2))$ and three-month-ahead contracts $r_m - F_4(d^{\dagger}(m-3))$ have comparable improvements (69% and 64%, respectively) relative to the forecast errors assuming no change ($r_m - r_{m-2}$ and $r_m - r_{m-3}$, respectively).

In more recent years, the futures prices have become quite astounding in the accuracy of their predictions. For data over 2003:01 through 2006:06, they offer 97% improvements in mean squared error for purposes of predicting the fed funds rate relative to a random walk.

I conclude that while one can find some statistical evidence of predictability of $f_i(d)$, any daily fluctuations in the implicit risk premium could at most account for a very small part of the variance of $f_i(d)$. Instead, daily changes in $f_i(d)$ primarily reflect changes in market participants' assessments of where the federal funds rate is likely to be over the next few months. Particularly in recent years, markets to a very good job in making this assessment.

2.2 Summarizing new information about Fed policy.

The data described above register three conceptually different things that the market may have learned on day d about the near-term course of Fed policy. The news on day d may have warranted a revision in the expectation of the fed funds rate for the current month ($f_1(d)$), the following month ($f_2(d)$) or the month after that ($f_3(d)$). Of course, these 3 variables are far from independent– the correlation between $f_2(d)$ and $f_3(d)$, for example, is 0.90. Thus, while one could in principle ask what would happen if $f_2(d)$ were to increase with $f_3(d)$ constant, in practice such a thought experiment is quite dissimilar to what has typically been experienced. On the other hand, the variable $f_3(d) - f_2(d)$ has a correlation of only 0.13 with $f_2(d)$, so it is quite natural to regard $f_2(d)$ and $(f_3(d) - f_2(d))$ as two separate, largely uncorrelated shocks. I have for this reason found it instructive to summarize changes in market expectations about near-term monetary policy in terms of the level, slope, and curvature of the implied term structure for fed funds, where

$$\ell(d) = f_2(d)$$

$$s(d) = f_3(d) - f_2(d)$$

$$c(d) = f_3(d) - 2f_2(d) + f_1(d).$$

The fitted values of a regression on $(f_1(d), f_2(d), f_3(d))'$ are of course numerically identical to those for a regression on $(\ell(d), s(d), c(d))'$, and the coordinate system in which results are reported below is simply a rotation of corresponding results that could be expressed in terms of the original $f_i(d)$. Where these regressions differ is in the nature of the partial derivative questions to which individual regression coefficients represent the answer. In a regression on $(\ell(d), s(d), c(d))'$, the coefficient on $\ell(d)$ is telling us what would happen if $\ell(d)$ were to increase with $s(d)$ and $c(d)$ were constant, in other words, the coefficient on the level $\ell(d)$ is the answer to the question, what would happen if the market's expectation of the fed funds rate for the current month, the following month, and the month after that were all to increase together by 1 basis point.[5] The coefficient on the slope $s(d)$ indicates the consequences if we were told that the fed funds rate is going to be rising by 1 basis point per month for each of the following two months. Finally, the curvature $c(d)$ tells us what would happen if the fed funds rate is expected to increase at a faster rate between next month and the following relative to the increase between this month and next.

3 Mortgage rates.

3.1 Data description.

A survey of U.S. national average mortgage rates is reported weekly by the Federal Home Loan Mortgage Corporation (Freddie Mac), and available from FRED, the databank of the Federal Reserve Bank of St. Louis. These data were released on Fridays from April 2, 1971 to January 2, 2004, and have been released on Thursdays since January 8, 2004. The empirical estimates in this section are all based on the weekly change in this series measured in basis points, denoted ΔR_w, for the period since fed funds futures have been traded.

[5] Selecting $f_2(d)$ as the basis for the level rather than $f_1(d)$ is warranted by the fact that it is closer to being a factor for $(f_1(d), f_2(d), f_3(d))'$ than is $f_1(d)$, and also tends to have a stronger correlation with other macro variables of interest than does $f_1(d)$. For these reasons, $f_2(d)$ is a more logical candidate to represent the overall level of the near-term fed funds term structure than is $f_1(d)$.

3.2 Martingale approximation.

The appendix reviews why a 30-year fixed mortgage rate, when sampled at very high frequencies, should approximately follow a martingale. We indeed find very little empirical predictability in changes in the weekly series. In a regression of the 922 observations from $w =$ November 4, 1988 through June 29, 2006 on a constant and three lags,

$$\Delta R_w = \underset{(0.33)}{-0.30} + \underset{(0.033)}{0.081}\Delta R_{w-1} + \underset{(0.033)}{0.028}\Delta R_{w-2} + \underset{(0.033)}{0.105}\Delta R_{w-3} + \hat{e}_w, \quad (3)$$

the constant is statistically insignificant while the coefficients on lags 1 and 3 are statistically significant. The magnitude of this serial correlation is quite small; the R^2 of the above regression is only 0.02. We will nevertheless retain the constant term and 3 lags as a base case for all the other regressions reported in this paper.

There does not seem to be any evidence of further predictability in this series beyond this very modest serial correlation, as detailed in Table 1. Weekly or monthly lags of mortgage rates have no predictive power, nor do any of the variables proposed by Piazzesi and Swanson (forthcoming) to predict fed funds futures.[6] The R^2 of each of the 9 regressions summarized in Table 1 is still only 0.02. I conclude that treating daily values of the mortgage rate as a martingale is an excellent approximation that appears to be quite consistent with the data.

[6] For yield spreads, this was based on the value of the relevant interest rates that would have been known 3 days prior to the release day for week $w - 1$. For example, for week $w =$ June 29, 2006, the previous week's reporting day was Thursday, June 22, so the interest rates used are for the first business day prior to Monday, June 19, which was Friday, June 16. The reason for lagging interest rates by 4 days in this way will be explained shortly.

3.3 Comovement with fed funds futures.

Under the martingale hypothesis, daily changes (or, more generally, daily innovations) in the mortgage rate are driven by previously unavailable information about interest rates and discount factors. One component of this news must include revised expectations about what the Fed is going to do over the very near future. For the time being, we will draw no distinction between news about the Fed itself and news about the economy to which both the Fed and mortgage rates may be responding. Instead, we focus on the following conditional forecasting question: suppose some news arrives on day d that causes us to revise our predictions of what the Fed is going to do over the near future. How would we revise our expectation of the mortgage rate in response to that news? If daily data were available, we could find the answer to that forecasting question by estimating the values of θ_j in the following regression:

$$R(d) - R(d-1) = \theta_1 \ell(d) + \theta_2 s(d) + \theta_3 c(d) + e(d) \tag{4}$$

where $e(d)$ and each of the regressors would be expected to be approximate martingale difference sequences.

Expression (4) further implies that if we performed a regression of the change in mortgage rates over a small interval of q days on news about the Fed's plans that arrived over each of the intervening days,

$$R(d) - R(d-q) = \sum_{j=1}^{q} \beta_{1j} \ell(d-j) + \sum_{j=1}^{q} \beta_{2j} s(d-j) + \sum_{j=1}^{q} \beta_{3j} c(d-j) + \varepsilon(d) \tag{5}$$

we should find $\beta_{ij} = \theta_i$ for $i = 1, 2, 3$ and $j = 1, 2, ..., q$ where $\{\varepsilon(d), \varepsilon(d-q), \varepsilon(d-2q), ...\}$

would again be a martingale difference sequence since $\varepsilon(d) = e(d) + e(d-1) + \cdots + e(d-q+1)$.

Consider, then, a regression of the weekly change in mortgage rates on daily innovations in the level, slope, and curvature of fed funds futures prices. Let ℓ_{w1} denote the change in the level of the fed funds futures on the day on which the week w mortgage rate would normally be released, if the Chicago Board of Trade was open on that day, while ℓ_{w1} is defined to be zero if the Chicago Board of Trade was closed on that day. Thus prior to 2004, ℓ_{w1} is based on the change on Friday for a fed funds contract settled in the following month, while ℓ_{w1} would represent a Thursday change for weeks w since 2004. Let ℓ_{w2} denote the change on the preceding day (namely, Thursdays prior to 2004, Wednesdays since) if data are available for that day and zero otherwise. Thus $(\ell_{w1}, \ell_{w2}, ..., \ell_{w,13})'$ collects all the changes in the month-ahead fed futures for the 13 most recent usual business days prior to and including the usual release day. Collect changes in the slope and curvature in analogous vectors $(s_{w1}, s_{w2}, ..., s_{w,13})'$ and $(c_{w1}, c_{w2}, ..., c_{w,13})'$.

Figure 3 plots the coefficients and 95% confidence intervals on changes in level, slope, and curvature in the regression

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=1}^{13} \left(\beta_{1j} \ell_{wj} + \beta_{2j} s_{wj} + \beta_{3j} c_{wj} \right) + \varepsilon_w. \tag{6}$$

For example, the top panel plots β_{1j} as a function of j. It is quite striking that there are no effects of changes in fed funds futures on mortgage rates for the first 3 days.

In the current system in which the weekly mortgage data are released on a Thursday, Freddie Mac officials tell me they stop collecting numbers on Wednesday, and that most of the reports from individual banks come in on Monday or Tuesday. For a quote from an individual bank that Freddie Mac receives on Monday, it would be physically impossible for the unpredicted movements in fed funds futures on Tuesday, Wednesday, or Thursday (which in turn are reflected in the values of ℓ_{wj}, s_{wj}, and c_{wj} for $j = 3, 2$, and 1, respectively) to have any effect on the reported mortgage. Moreover, banks that do report on Tuesday could well be submitting a rate that was set on Monday, in which case ℓ_{w3} would again not affect the value of R_w.

Although there are doubtless some differences in the specific day and nature of the number that different sources report to Freddie Mac, it is interesting to consider what we would expect to find in (6) if we considered R_w to be a uniform value determined on Monday (that is, the day corresponding to ℓ_{w4}), and if the framework proposed in (5) were valid. In that case, we would predict that (1) the coefficients on β_{ij} should all be zero for $j \in \{1, 2, 3\}$, since these reflect information that came in after the time at which R_w was set; (2) the coefficients on β_{ij} should also be zero for $j \in \{9, 10, 11, 12, 13\}$, since information arriving on these days should have already been reflected in the value of R_{w-1}; and (3) the coefficients β_{1j} should all be the same for $j \in \{4, 5, 6, 7, 8\}$, since these are just alternative estimates of the single number θ_1; likewise the β_{2j} should all equal θ_2 and the β_{3j} should all equal θ_3 for $j \in \{4, 5, 6, 7, 8\}$. Formal tests of these hypotheses all turn out to be accepted[7]
. One might see a suggestion in Figure 3 that β_{14} and β_{24} are smaller than the others, which would be consistent with the claim that a fraction of the banks are reporting values set on Friday. That hypothesis would also imply a nonzero value for β_{19} and β_{29}, which

[7] A joint test of hypotheses (1) and (2) produces an F(24,879) statistic of 0.94 (p value of 0.55). A test of hypothesis (3) results in F(36,879) = 1.32 (p = 0.10).

again is suggested by the figure at least for β_{29}. But while that alternative hypothesis is quite plausible and hinted at by the point estimates, the evidence for it is not statistically significant. Furthermore, any modification of the statement of the results in this direction would lend even more credence to the claim that (4) is the correct theoretical framework for predicting how daily mortgage rates would behave if we had accurate daily data available. For purposes of having a formal null hypothesis to test, I will maintain the view that ΔR_w can be interpreted as the Monday-to-Monday change in an implicit daily mortgage series.

Note further that the curvature coefficients β_{3j} do not appear to contributing anything for any j, a hypothesis one readily accepts with an $F(13{,}879)$ statistic of 0.78 (p value of 0.68).

Coefficient estimates that result from imposing hypotheses (1) and (2) above, that is, from estimation of

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=4}^{8} \left(\beta_{1j} \ell_{wj} + \beta_{2j} s_{wj} \right) + \varepsilon_w \tag{7}$$

are reported in the first 5 rows of Table 2. It is natural to interpret the values $\hat{\beta}_{1j}$ as 5 independent estimates of θ_1. These estimates all suggest a value of θ_1 around 0.5, meaning that if something causes market participates to raise their estimate of the near-term level of the fed funds rate by 10 basis points, the 30-year mortgage rate would go up by 5 basis points. The slope coefficients $\hat{\beta}_{2j}$ in (7) likewise give 5 independent estimates of θ_2, each of which suggests a value for θ_2 around 1.3, meaning if the rate at which the Fed is expected to be raising interest rates goes up by 10 basis points per month, the mortgage rate would rise by 13 basis points.

The theoretical framework and statistical acceptance of hypothesis (3) above imply that we could better estimate θ_1 and θ_2 by combining the information across days of the week,

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \theta_1 \sum_{j=4}^{8} \ell_{wj} + \theta_2 \sum_{j=4}^{8} s_{wj} + \varepsilon_w,$$

as in row (6) of Table 2. The R^2 of the above regression is 0.35, meaning that about a third of the variance of weekly changes in mortgage rates is accountable by new information about what the federal funds rate is likely to be over the next few months.

Stretching the maintained assumption that daily changes in the risk premium are negligible on into months may be questionable, but it is interesting to predict what should happen over longer intervals again under the stark hypothesis that (4) is exactly true. We can construct an artificial monthly series, properly and consistently aggregated, as follows. Let $\tilde{R}_{m1}$ be the mortgage rate for the last week whose release date falls within month m. Let $\tilde{R}_{m2}$ be the mortgage rate for the week before that (the next-to-last week of the month), and so on. Our focus will be on the value of $\tilde{R}_{m1} - \tilde{R}_{m5}$, which corresponds to the cumulative change in the mortgage over the last four weeks of month m. If the weekly series R_w were a martingale, then the monthly series $\tilde{R}_{m1} - \tilde{R}_{m5}$ would be uncorrelated with $\tilde{R}_{m-1,1} - \tilde{R}_{m-1,5}$.

Let $\tilde{\ell}_{m1}$ denote the cumulative change in the expected level of the fed funds rate over the 5 days associated with $\tilde{R}_{m1}$, that is, if $w^*(m)$ denotes the last week of month m, then

$$\tilde{\ell}_{m1} = \sum_{j=4}^{8} \ell_{w^*(m),j}. \tag{8}$$

Let $\tilde{\ell}_{m2}$ denote the cumulative level change for the week before that, and let $\tilde{s}_{mk}$ denote analogous cumulative slope changes for various weeks of month m. The weekly martingale hypothesis would then imply that in the monthly regression,

$$\tilde{R}_{m1} - \tilde{R}_{m5} = \tilde{c} + \sum_{k=1}^{4} (\tilde{\beta}_{1k} \tilde{\ell}_{mk} + \tilde{\beta}_{2k} \tilde{s}_{mk}) + \tilde{\varepsilon}_m$$

the error $\tilde{\varepsilon}_m$ should again be serially uncorrelated and the coefficients $\tilde{\beta}_{1k}$ would give us 4 independent estimates of the same structural coefficient θ_1 hypothesized to be governing the underlying latent daily relation; $\tilde{\beta}_{2k}$ likewise give us 4 estimates of θ_2. These estimates are reported in rows (7)-(10) of Table 2. The estimates for θ_1 tend to be a little smaller and those for θ_2 a little bigger than those obtained from the original weekly data, though confidence intervals for each separate estimate easily include the predicted value. Again we accept the hypothesis ($F(6, 203) = 0.97$, $p = 0.45$) that the coefficients $\tilde{\beta}_{1k}$ are all the same, as are the $\tilde{\beta}_{2k}$. Imposing this restriction gives yet another new pair of estimates in row (11) of Table 2 that are quite consistent with all the others that have been obtained.

3.4 Invariance of the correlations.

The estimates presented so far simply summarize the comovement between fed funds futures and 30-year mortgage rates, without attempting to identify whether mortgage rates are responding to news about the Fed or whether both the Fed and mortgage rates are responding to general news about the economy. In this section we explore how these correlations differ as a function of the source of news that appears to be hitting the market.

The first way I addressed this was by singling out those days for which Gürkaynak, Sack, and Swanson (2005b) identified monetary policy statements to be the key factor driving changes in the fed funds futures markets. There are 139 such days (all between 1990 and

2005) within the sample. Let $a_{w1}^{[MP]} = 1$ if the day on which R_w would usually be reported happened also to be a day on which Gürkaynak, Sack, and Swanson determined that a major policy announcement was issued, with $a_{w1}^{[MP]}$ otherwise defined to be zero. Let $a_{w2}^{[MP]} = 1$ if a policy announcement occurred on the previous day, and so on. I reproduced (7) using only fed funds futures changes on days for which $a_{wj}^{[MP]} = 1$:

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=4}^{8} a_{wj}^{[MP]} \left(\beta_{1j}^{[MP]} \ell_{wj} + \beta_{2j}^{[MP]} s_{wj} \right) + \varepsilon_w. \tag{9}$$

The estimated values for $\beta_{kj}^{[MP]}$ are reported in rows (12) through (16) of Table 2. This is asking a lot of the data, since there there are typically only 28 observations relevant for estimating a given coefficient $\beta_{ij}^{[MP]}$, and this is reflected in large standard errors.[8] Even so, the level coefficients on the third and fifth day of the week are each statistically significantly different from zero, all 10 estimated coefficients are positive, and all are within the range, given the standard errors, of values that would be expected if they were providing estimates of the same values θ_1 and θ_2 identified in earlier rows in the table. One can formally test that equivalence by testing H_0: $\lambda_{kj}^{[MP]} = 0$, $j = 4, ..., 8$, $k = 1, 2$ in

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=4}^{8} \left(\beta_{1j} \ell_{wj} + \beta_{2j} s_{wj} \right) + \sum_{j=4}^{8} a_{wj}^{[MP]} \left(\lambda_{1j}^{[MP]} \ell_{wj} + \lambda_{2j}^{[MP]} s_{wj} \right) + \varepsilon_w. \tag{10}$$

This hypothesis is accepted ($F(10, 898) = 1.61$, $p = 0.10$).

One can get considerably more power by grouping the five days together, and indeed one accepts the hypothesis that $\beta_{1j}^{[MP]} = \theta_1^{[MP]}$, $\beta_{2j}^{[MP]} = \theta_2^{[MP]}$ for $j = 4, ..., 8$ in (9) ($F(8, 908) =$

[8] The deterioration in standard errors between rows (1)-(5) and (12)-(16) is not as great as one might have expected given the huge reduction in the number of useful observations because a disproportionately large share of the variance of ℓ_{wj} and s_{wj} is accounted for by those days for which $a_{wj}^{[MP]}$ is nonzero.

0.76, $p = 0.64$). Imposing this hypothesis, the implied estimates of $\theta_1^{[MP]}$ and $\theta_2^{[MP]}$ from

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=4}^{8} a_{wj}^{[MP]} \left(\theta_1^{[MP]} \ell_{wj} + \theta_2^{[MP]} s_{wj} \right) + \varepsilon_w \tag{11}$$

then have much more accuracy, and are extremely close to those obtained from the full sample, as seen in row (17) of Table 2.

I found similar results using only data from days on which other particular announcements are made. For example, let $a_{wj}^{[CU]} = 1$ if a capacity utilization figure was released on day j of week w, with $a_{wj}^{[CU]} = 1$ otherwise.[9] Although these release dates do not allow one to estimate each individual day effect, one can calculate effects cumulating over the week, replacing $a_{wj}^{[MP]}$ in (11) with $a_{wj}^{[CU]}$. Note that such an estimate makes no use of changes in fed funds futures on any day other than those on which capacity utilization data are released, and one would expect that this particular news was a key factor accounting for the variation in ℓ_{wj} and s_{wj} on these days. Yet we find in row 1 of Table 3 that the response of mortgage rates to new information about near-term fed funds rates is virtually the same as any of the estimates from Table 2, and again we formally accept the hypothesis that capacity utilization announcement days are the same as any other; that is, the test of $\lambda_1^{[q]} = \lambda_2^{[q]} = 0$ for $[q] = [CU]$ in

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \sum_{j=4}^{8} (\theta_1 \ell_{wj} + \theta_2 s_{wj}) + \sum_{j=4}^{8} a_{wj}^{[q]} \left(\lambda_1^{[q]} \ell_{wj} + \lambda_2^{[q]} s_{wj} \right) + \varepsilon_w$$

is readily accepted ($F(2, 906) = 0.01$, $p = 0.99$). The same is true if we only use those days on which unemployment or the consumer price index are released (see Table 3). Release of

[9] These dates were taken from MMS data kindly provided me by Andra Ghent.

the consumer confidence numbers does not seem to have much effect on fed funds futures, so the standard errors if we were forced to rely on only these days are quite big (row 4), though again the estimates using only these days are statistically consistent with those for all other days.

We are now in a position to draw the following conclusions. Suppose we are given information that the Federal Reserve is going to be setting a level for the fed funds rate over the next several months that is 10 basis points higher than we had previously anticipated. We would then expect to see an upward revision in the 30-year mortgage rate of 5 basis points. Likewise, news that causes us to revise upward by 10 basis points per month the rate at which the Fed is going to be raising the fed funds rate over the next several months would lead us to expect a 13-basis-point increase in the mortgage rate. And we would not particularly care whether the news that caused us to change our anticipations of the fed funds rate was based on an announcement made by the Fed or release of new information about output, employment, or inflation– if we change our expectation of what the Fed is going to do for whatever reason, the data suggest a similar change in the mortgage rate. The results further imply that any changes in Fed policy will show up in mortgage rates the instant that they become anticipated by markets, and that the only way the Fed could change mortgage rates is by doing something unanticipated by the market.

Given these results, suppose that the Fed Chair were then to ask us, What do you expect to happen to mortgage rates if I raise the level of the fed funds rate by 10 basis points? A reasonable answer to give would be, we expect the mortgage rate to rise by 5 basis points.

In the following section, we extend these results to predicting the consequences for the number of new homes sold.

4 New home sales.

4.1 Mortgage rates and new home sales.

The primary data on home sales used here are the seasonally unadjusted monthly values for the number of new homes sold, as reported by the Census Bureau and obtained from the Webstract database (series HZNS). Let h_m denote 100 times the natural logarithm of this series for month m, y_m denote the rate of growth of real GDP for the most recently completed quarter prior to month m, and $\Delta\tilde{R}_{mj}$ the change in the weekly mortgage rate for the jth most recent week counting backwards from the last week of month m. For example, for m corresponding to June 2006, $\Delta\tilde{R}_{m1}$ is the difference between the mortgage rate reported on Thursday, June 29, 2006 and that for June 22, while $\Delta\tilde{R}_{m6}$ is the change between May 18 and May 25. I explored a regression of h_m (for m = February 1989 to June 2006) on seasonal dummies for each of the 12 months, 5 of its own lags, a linear time trend, the prior quarter's GDP growth, and changes in the mortgage rate for the 30 most recent weeks,

$$h_m = \sum_{j=1}^{12} \gamma_{0j} d_{mj} + \sum_{j=1}^{5} \gamma_{1j} h_{m-j} + \gamma_{21} m + \gamma_{22} y_m + \sum_{j=1}^{30} \gamma_{3j} \Delta\tilde{R}_{mj} + \varepsilon_m \qquad (12)$$

where $d_{m1} = 1$ if month m is January and zero otherwise. The estimated coefficients on the variables other than the lagged mortgage rates are reported in Table 4. For this estimation, the sample size is 209 months and the R^2 is 0.97.

New home sales are highly seasonal, with most sales coming in the spring and summer.

Regression (12) models home sales as stationary around monthly dummies and time trend, with the sum of lag coefficients coming to 0.83. Additional lags of home sales or GDP growth, or measures of inflation based on the one-quarter or 12-month change in the personal consumption expenditures deflator, do not enter statistically significantly.

The coefficients on weekly mortgage rates for this regression, along with 95% confidence intervals, are plotted in the top panel of Figure 4. Recalling that these regressors $\Delta\tilde{R}_{mj}$ are essentially independent of each other, the large block of coefficients with t-statistics around -2 for lags 6 through 23 is extremely statistically significant. Nor are these long lags an artifact of using the lagged changes rather than levels of mortgage rates as explanatory variables– if one adds the current level of the mortgage rate or the past log level of GDP to the above regression, the new coefficients on levels are statistically insignificant and the long lags on $\Delta\tilde{R}_{mj}$ remain. The regression indicates that, if your goal is to forecast home sales, it pays to look not just at seasonals, GDP growth, trend, and lags of home sales, but also what the mortgage rates have been every week for the last 6 months.

4.2 Interpreting the lags.

What could account for such long lags? One's first guess might be delays between the signing of a contract and the completion of escrow, but that can not explain the findings here, since the Census counts a home as being sold on the date the contract is signed rather than the date of escrow. A second, more promising hypothesis is that for many people, there is a substantial lag between the time at which they decide to buy a home and the time at which they find the particular home they want and are able to buy.

The National Association of Realtors conducts a survey of individuals who buy a home, asking, "How long did you actively search before you located the home you eventually purchased?" The top panel of Figure 5 plots the cross-section distribution of search times from their 2005 Profile of Home Buyers and Sellers.[10] There is clear measurement error in these data, with respondents much more likely to report multiples of 4 weeks and considerable clumping at 52-week and more-than-99-week searches. Insofar as these simply represent rounding of the original true values, ignoring this clumping is unlikely to matter for the statistics reported below, which make no effort to model these reporting regularities.

A Weibull density is often used to describe a cross-section distribution of search times. Let j denote the number of weeks a household says it spent searching, k the shape parameter, and λ the scale parameter:

$$f(j;k,\lambda) = \frac{k}{\lambda}\left(\frac{j}{\lambda}\right)^{k-1} \exp\left\{-(j/\lambda)^k\right\}; \qquad k,\lambda,j > 0. \tag{13}$$

Maximum likelihood estimates of the parameters for the search distribution based on the cross-section data[11] are reported in the first panel of Table 5. These estimates imply that households spent an average of 14.9 weeks searching before purchasing a home.

Consider the implications for the time series regressions if there is a cross-sectional heterogeneity in search times represented by (13). Let $\tilde{S}_{mj}$ denote the total number of households searching for a home as of the jth week counting backward from the end of month m and $\tilde{H}_{mj}$ the actual number of houses sold that week. Suppose that the log of the number of

[10] I am grateful to NAR for providing me with this data.

[11] I associated a reported search time of j weeks with the midpoint between j and $j+1$ in order to allow evaluation of (13) for a search time of $j = 0$ weeks when $k < 1$.

people searching is a linear function of the interest rate,

$$\frac{\partial \tilde{S}_{mj}}{\partial \tilde{R}_{mj}} = \overline{\alpha}^* \tilde{S}_{mj},$$

in which $\overline{\alpha}^*$ gives the proportionate decrease in house-searchers resulting from a 1-basis-point increase in the mortgage rate. If $f(j; k, \lambda)$ of these searchers would have otherwise succeeded in purchasing a house during the last week of month m, then

$$\frac{\partial \tilde{H}_{m1}}{\partial \tilde{R}_{mj}} = \overline{\alpha}^* \tilde{S}_{mj} f(j; k, \lambda). \tag{14}$$

If month m consisted of exactly 4 weeks, then the change in H_m, the level of month m's home sales, would be

$$\frac{\partial H_m}{\partial \tilde{R}_{mj}} = \overline{\alpha}^* \tilde{S}_{mj} g_W(j; k, \lambda)$$

where

$$g_W(j; k, \lambda) = \sum_{i=\max\{1, j-4\}}^{j} f(i; k, \lambda)$$

Let ς denote the average ratio of searchers to monthly sales and approximate $\tilde{S}_{mj}/H_m \simeq \varsigma$. Then for $h_m = 100 \log(H_m)$,

$$\frac{\partial h_m}{\partial \tilde{R}_{mj}} \simeq \alpha g_W(j; k, \lambda)$$

where $\alpha = 100\overline{\alpha}^* \varsigma$, that is, α measures the decrease in home searchers as a percent of monthly sales that results from a 1-basis-point increase in the mortgage rate.

These considerations suggest an approach similar to that in Jung (2006), who related the time-series delays in the impulse-response function between monthly fed funds rate innovations and subsequent investment spending to the distribution across investment projects in the time required for completion as estimated from cross-section surveys. Here, I propose to replace (12) with

$$h_m = \sum_{j=1}^{12} \gamma_{0j} d_{mj} + \sum_{j=1}^{5} \gamma_{1j} h_{m-j} + \gamma_{21} m + \gamma_{22} y_m + \alpha \sum_{j=1}^{30} g_W(j; k, \lambda) \Delta \tilde{R}_{mj} + \varepsilon_m. \qquad (15)$$

This also will be recognized as an alternative strategy to those proposed by Ghysels, Santa-Clara, and Valkanov (2004) for selecting a parsimonious representation of the dynamics implied by a regression such as (12).

The parameter vector $\boldsymbol{\theta} = (\alpha, k, \lambda, \boldsymbol{\gamma}_0', \boldsymbol{\gamma}_1', \boldsymbol{\gamma}_2', \sigma)'$ was then estimated by maximum likelihood assuming $\varepsilon_m \sim N(0, \sigma^2)$, or equivalently by nonlinear least squares. Noting that (15) is essentially a restricted version[12] of (12), we can test the appropriateness of this specification with a likelihood ratio test, whose $\chi^2(27)$ statistic has a p-value of 0.09. The resulting estimates of α, k, and λ are reported in the second panel of Table 5. If for illustration 1/5 of the people searching succeed in buying a home each month ($\varsigma = 5$), then the estimate $\hat{\alpha} = -0.2$ would imply that $100\overline{\alpha}^* = -0.04$, meaning that a 100-basis-point increase in the mortgage rate leads to a 4% reduction in the number of people who are trying to purchase a new home. The values of k and λ estimated from the time-series relation imply a mean search time of 13.4 weeks, quite similar to the value of 14.9 weeks obtained from the cross-section estimates in panel 1. Restricting the coefficients in this way tremendously improves the precision of the estimated effect of mortgage rates on new home sales, whose coefficient α now has a t statistic of -5.5.

[12] I am ignoring here the fact that (15) includes coefficients on $\Delta \tilde{R}_{mj}$ for $j > 30$ which are not in (12). This is appropriate since these predicted values are less than 10^{-3} in absolute value.

The restricted values for the coefficients on lagged mortgage rates are plotted in the second panel of Figure 4. The distribution implies that consumers are distributed across a broad range of search times. Although one can say with a good deal of confidence that mortgage rates have a big effect on home sales and that this effect is broadly spread out over a 1- to 6-month interval, alternative specifications of the distribution would also fit the data. For example, the third panel of Figure 4 reports the results of assuming simply a uniform distribution between $j = 6$ and 23 weeks, numerically equivalent to replacing the thirty variables $\left\{\Delta\tilde{R}_{mj}\right\}_{j=1}^{30}$ with the single regressor $\tilde{R}_{m6} - \tilde{R}_{m,24}$, i.e., the cumulative change in the mortgage rate between 24 and 6 weeks earlier. This specification uses 2 fewer parameters (if one ignores the implicit parameter choice of having used 6 and 24 as endpoints of the distribution) than (15), and achieves a value for the log likelihood that is only 0.4 below that of (15). I nonetheless find (15) a slightly more attractive formulation, since it seems unlikely that the effect would be literally zero for $j < 6$ or > 23, and since it offers a cleaner treatment of exactly what has been estimated from the data.

Although the mean lag of the distributions implied by the estimates in panel 1 and panel 2 of Table 5 are similar, the shapes (compared in the second and third panels of Figure 5) are statistically significantly different. The time-series relations imply an increasing hazard rate ($k > 1$) while the cross-section hazard rate is nearly constant. There are two reasons why we might expect these distributions to be different. First, the cross-section distribution includes a number of households with very long search times of 1 or 2 years, for which it seems implausible that the mortgage rate prevailing 1 or 2 years previous is a key determinative factor. If these long-time searchers do not play a material role in the time-series lags, one would expect the mean delay as estimated by the time-series regression to be shorter than that from the cross-sectional analysis. Second, following Reis (2006), it seems natural to posit that there is some heterogeneity across households in the time required to receive and process information about changes in mortgage rates, introducing a heterogeneous delay between the time at which the mortgage rate changes and the time at which a household initiates or abandons a search for a new home. This factor would cause the mean lag from the cross-section estimates to be greater than that from the time-series analysis. The combined effect of the two factors could account for why the two distributions have the same mean, with the time-series distribution having less mass at very short or very long delays.

4.3 Linking home sales to monetary policy.

We motivated equation (12) as simply a forecasting regression, though the negative coefficients on lagged mortgage rates suggest it is primarily summarizing demand effects, and the specific restriction on those lags imposed in (15) was motivated by interpretation as a demand curve. We now propose that the inference from this restricted forecasting equation can be combined with the parameters from the preceding section to answer the question, What should the Federal Reserve expect to happen to new home sales if it raises the fed funds rate more than expected?

As support for this interpretation, we might first seek to isolate the effect on new home sales of that component of mortgage rate changes that are associated statistically with innovations in the fed funds rate by estimating equation (12) by 2SLS, using as instruments $\{\tilde{\ell}_{mk}, \tilde{s}_{mk}\}_{k=1}^{30}$, where as in (8) $\tilde{\ell}_{mk}$ is the cumulative innovations in the level in the kth week counting backward from the last week of month m. The non-mortgage-rate regressors in (12) were also used as instruments. The resulting 2SLS estimates of the coefficients on lagged mortgage rates are plotted in the last panel of Figure 4, along with 95% confidence intervals. The 2SLS estimates are less precise than the OLS estimates in the top panel, though two of the coefficients (lags 8 and 16) individually are statistically significant, and the broad pattern of negative coefficients between lags 6 and 21 is reproduced by the 2SLS estimates. Since there are two instruments (level and slope) for each mortgage rate, Hansen's J statistic (e.g., Hamilton, 1994, p. 421) can be used to test for the validity of the instruments. Alternatively, one can use the Durbin-Wu-Hausman test[13] for whether the OLS and 2SLS estimates are the same, or simply test whether $\{\tilde{\ell}_{mk}, \tilde{s}_{mk}\}_{k=1}^{30}$ should appear as additional OLS regressors in (12). As reported in the first row of Table 6, our results pass all three of these specification tests– one accepts the hypothesis that the predicted consequences for home sales of fed funds innovations are exactly those anticipated on the basis of the effect of those innovations on mortgage rates, and that the fed funds rate has no effect on new home sales other than that operating through changes in the mortgage rate.

One can obtain both more precise estimates and more powerful tests if we treat the values of $k = 3.24$ and $\lambda = 14.97$ as known and then use this same set of 79 instruments

[13] This is found by first regressing each $\Delta\tilde{R}_{mj}$ on the full set of instruments, adding these 30 residuals to (12), and then calculating the usual OLS F test for whether these 30 new coefficients are all zero. See equation (6) in Nakamura and Nakamura (1981).

to estimate the 20 parameters in (15) by 2SLS. The resulting estimate of $\hat{\alpha}_{2SLS} = -0.19$ turns out to be virtually identical to the value $\hat{\alpha}_{MLE} = -0.20$ reported in Table 5, and all 3 specification tests lead to acceptance of the null hypothesis that 30 weeks of lagged fed funds innovations contribute nothing to predicting new home sales beyond that captured by the single variable $Q_m = \sum_{j=1}^{30} g_W(j; k, \lambda)\Delta\tilde{R}_{mj}$, and that the predictive consequences for new home sales of that portion of movements in Q_m that could be explained statistically by fed funds innovations are identical to those inferred from an OLS regression on the restricted mortgage rate changes alone.

It is also interesting to use as instruments only fed funds innovations on days of significant monetary policy announcements, namely use as instruments for Q_m the values $\{\tilde{\ell}_{mk}^{[MP]}, \tilde{s}_{mk}^{[MP]}\}_{k=1}^{30}$ where for example $\tilde{\ell}_{mk}^{[MP]} = \sum_{j=4}^{8} a_{w^*(m)-k+1,.j}^{[MP]} \ell_{w^*(m)-k+1,j}$. Row 3 of Table 6 shows that we accept the hypothesis that the effects on new home sales of fed funds futures changes on days of monetary policy announcements are the same as those we would infer from the original forecasting equation (15).

It is also possible to examine the relation between new home sales and daily changes in fed funds futures. Let ℓ_{mj}^* denote the change in the level of the fed funds futures on the jth business day counting backwards from the last day of month m and let s_{mj}^* denote the change in the slope on that day. Consider the consequences of replacing (15) with a specification that depends on the change in level and slope over the most recent 125 business days.

$$h_m = \sum_{j=1}^{12} \gamma_{0j} d_{mj} + \sum_{j=1}^{5} \gamma_{1j} h_{m-j} + \gamma_{21} m + \gamma_{22} y_m$$
$$+\alpha_\ell \sum_{j=1}^{125} g_D(j; k_D, \lambda_D) \ell_{mj}^* + \alpha_s \sum_{j=1}^{125} g_D(j; k_D, \lambda_D) s_{mj}^* + \varepsilon_m \qquad (16)$$

where I assume 21 business days in the month:

$$g_D(j; k_D, \lambda_D) = \sum_{i=\max\{1, j-21\}}^{j} f(i; k_D, \lambda_D).$$

The earlier analysis allows us to predict what we should find from estimation of (16). The average week between January 1989 and June 2006 contained 4.8 business days. If the combined information-processing and search delays measured in weeks are distributed across households with a $W(k_W, \lambda_W)$ distribution, and if these delays are evenly distributed across business days within a given week, then the delays measured in days should have a $W(k_D, \lambda_D)$ distribution with the same shape parameter ($k_D = k_W$) and translated scale ($\lambda_D = 4.8\lambda_W$). From the estimates in Section 3, we would expect a 1-basis-point increase in ℓ_{mj}^* to translate into 0.5-basis-point increase in the mortgage rate quoted that day, implying $\alpha_\ell = 0.5\alpha_W$, while a 1-basis-point increase in s_{mj}^* would raise the mortgage rate by 1.3 basis points ($\alpha_s = 1.3\alpha_W$). This leads to predicted values for the coefficients reported in the third panel of Table 5, which are compared with those obtained by direct maximum likelihood estimation of (16). The standard errors are fairly big, and the level coefficient is not statistically significant. However, given the estimation uncertainty, the parameters are in the range of what we had expected, and a likelihood ratio test of the null hypothesis that the restrictions on k_D, λ_D, α_L, and α_S are all correct yields a $\chi^2(4)$ statistic of 8.31 (p-value

= 0.08), leading to acceptance of the null hypothesis. The search- and processing-time distribution implied by the daily time-series regression is converted back into units of weeks and plotted for comparison with those obtained by the other methods in the bottom panel of Figure 5.

4.4 Summarizing the dynamic consequences of monetary policy.

We are now in a position to answer the main question posed by this paper: If the Fed were to change its target for the fed funds rate, what would we expect to happen to new home sales? If the change were anticipated, the framework above implies there would be no effect. If the change is unanticipated, the dynamic consequences for new home sales would be identical regardless of the nature and timing of the change– as soon as any change is anticipated, that will translate into an immediate one-time shift in the mortgage rate, and this change will then feed into future home sales through the dynamics governed by the search parameters k and λ.

We can calculate the analog of a traditional impulse-response function as follows. I illustrate the implications for a change in $\tilde{R}_{m2}$, the next-to-last week of month m. The framework above implies $\partial\tilde{H}_{m2}/\partial\tilde{R}_{m2} = \overline{\alpha}^*\tilde{S}_{m2}f(1; k_W, \lambda_W)$ and $\partial\tilde{H}_{m1}/\partial\tilde{R}_{m2} = \overline{\alpha}^*\tilde{S}_{m2}f(2; k_W, \lambda_W)$. If, for illustration, the following month $m + 1$ has 4 weeks, then for home sales in each of that month's 4 weeks ($\tilde{H}_{m+1,j}$ for $j = 4, 3, 2, 1$) there is both the direct effect $\overline{\alpha}^*\tilde{S}_{m2}f(7-j; k_W, \lambda_W)$ and the indirect effect, the latter arising through the coefficient γ_{11} in (15) and resulting from the fact that the preceding month m has now seen a rise in sales:

$$\frac{\partial \tilde{H}_{m+1,j}}{\partial \tilde{R}_{m2}} = \overline{\alpha}^* \tilde{S}_{m2} f(7-j; k_W, \lambda_W) + \frac{\partial \tilde{H}_{m+1,j}}{\partial H_m} \frac{\partial H_m}{\partial \tilde{R}_{m2}}. \tag{17}$$

Here

$$\frac{\partial H_m}{\partial \tilde{R}_{m2}} = \frac{\partial(\tilde{H}_{m1} + \tilde{H}_{m2})}{\partial \tilde{R}_{m2}} = \overline{\alpha}^* \tilde{S}_{m2} f(1; k_W, \lambda_W) + \overline{\alpha}^* \tilde{S}_{m2} f(2; k_W, \lambda_W)$$

and evaluating the derivative $\partial \log H_{m+1} / \log H_m = \gamma_{11}$ at $H_{m+1} = H_m$,

$$\frac{\partial(\tilde{H}_{m+1,4} + \tilde{H}_{m+1,3} + \tilde{H}_{m+1,2} + \tilde{H}_{m+1,1})}{\partial H_m} = \gamma_{11}. \tag{18}$$

Imputing this monthly total equally to each week of the month and substituting into (17),

$$\frac{\partial \tilde{H}_{m+1,j}}{\partial \tilde{R}_{m2}} = \overline{\alpha}^* \tilde{S}_{m2} f(7-j; k_W, \lambda_W) + (\gamma_{11}/4)[\overline{\alpha}^* \tilde{S}_{m2} f(1; k_W, \lambda_W) + \overline{\alpha}^* \tilde{S}_{m2} f(2; k_W, \lambda_W)]$$

for $j = 1, 2, 3, 4$. One can iterate into future weeks in this fashion, analogous to calculating a standard impulse-response function, except that the calculations depend on the number of weeks comprising each month during the process. To summarize the typical response lag, I performed the above calculations starting for every week from October 7, 1988 to May 20, 2004. The average of these functions across all weeks is plotted in Figure 6, standardized for a change in mortgage rates of 10 basis points. This calculation implies that the maximal consequences of an increase in mortgage rates is not observed until 15 weeks later, at which time we would predict new home sales to be 1.04 basis points lower if there is a 10-basis-point increase in mortgage rates today.

As a result of the way the mortgage rate has been observed to respond to news, the dynamic consequences of any unanticipated change in Fed policy have exactly the same shape as the curve in Figure 6. For example, Figure 6 could equally well be described as the dynamic response of new home sales to a 20-basis-point increase in the level of the fed funds term structure, or also as the response to a $10/1.3 = 7.7$-basis-point increase in its slope.

Given the long lags between a change in policy and the effects on the economy, we are often in a situation where some monetary easing has followed a period of tightness, and policy makers would like to know, When will the recent easing start to counteract the previous tightening? The framework here provides us with a concrete basis for answering such questions. Let $H(d)$ denote the number of homes sold and $S(d)$ the number of people searching on day d. As in (14) we expect that

$$\begin{aligned} 100\frac{\partial \log H(d)}{\partial \ell(d-j)} &= (100)(0.5)\overline{\alpha}^* \frac{S(d-j)}{H(d)} f(j+1; k_D, \lambda_D) \\ &= \frac{H_{m^*(d)}}{H(d)} \frac{100\overline{\alpha}^* S(d-j)}{H_{m^*(d)}} f(j+1; k_D, \lambda_D) \\ &\simeq 20.9(0.5)\alpha_W f(j+1; k_W, \lambda_W) \end{aligned}$$

with 20.9 business days in a month. This gives us a way to summarize on a daily basis the implications for today's home sales of previous unanticipated monetary policy moves through calculation of

$$\xi(d) = (20.9)\alpha_W \left[0.5 \sum_{j=1}^{125} f(j-0.5; k_D, \lambda_D)\ell(d-j+1) + 1.3 \sum_{j=1}^{125} f(j-0.5; k_D, \lambda_D) s(d-j+1) \right]. \tag{19}$$

I calculated the value of this number for every day d in the sample using $\alpha_W = -0.20$, $k_D = 3.24$, and $\lambda_D = 71.85$. This index is characterized by an average value of zero by construction, given that the surprises $\ell(d)$ and $s(d)$ have mean zero. A negative value means that, on balance over the last half year, the Fed has surprised the market by being more contractionary at the 1-3 month horizon than markets had anticipated. The units of this index are in terms of the consequences that historical fed funds rate surprises are imputed to be having (in percentage terms) for current home sales. For example, a value of $\xi(d) = -5$ means that the home sales on day d are expected to be 5% lower than one would have predicted had the Fed behaved exactly as markets had been anticipating over the prior 6 months.

The value of this index is plotted in Figure 7. It is rarely observed to exceed 5% in absolute value, with the most significant historical contractions appearing prior to the recession of 1990, the economic slowdown of 1994, and the recession of 2001. The most recent episode of Fed tightening in fact did not surprise the markets very much, and accordingly is not regarded as that unusual by this metric. Instead, the dominant feature of Fed policy during the last decade is judged to be the aggressively expansionary policy in 2001-2002.

4.5 Application: monetary policy and the summer of 2006.

Figure 8 displays post-sample data[14] on the changing predictions for the August, September, and October fed funds futures contracts during the summer of 2006. In early summer, traders were anticipating a hike from the then-prevailing 5.25% up to 5.5% by the fall. During July, the market changed this assessment, becoming persuaded (correctly, as it turned

[14] Fed funds futures data subsequent to June 30, 2006 were downloaded from the now-defunct website http://www.spotmarketplace.com/futures/prices/ and represent closing rather than settlement prices. Note that these post-June data were not used in any of the preceding statistical analysis.

out) by the end of August that no rate changes would be forthcoming.

These changing expectations produced changes in both the level and the slope of near-term fed funds futures. According to the framework presented in Section 3, the fact that the Fed ended up choosing a lower target and slower rate of increase for August through October than the market had been anticipating as of the start of July would be expected to bring a reduction in the 30-year mortgage rate. The upper solid line in Figure 9 summarizes this prediction, by taking (1/2) of the cumulative change from July 3 through the indicated date in the 1-month-ahead fed funds rate, and adding it to 1.3 times the cumulative change in the 2-month-ahead minus the 1-month-ahead rate. The lower dashed line indicates the actual cumulative change in the mortgage rate. About a third of the 32-basis-point decline in the mortgage rate during July and August could be attributed to the fact that lenders became persuaded that the Fed was going to be less restrictive in August through October than the market had previously been anticipating.

One important practical challenge for the Fed is making decisions given the long delays between changes in policy and the effects on variables such as home sales. An unanticipated monetary policy stimulus, as measured by a sequence of negative values for $\ell(d)$ and $s(d)$, began July 13 . However, according to the estimates presented here, the maximal effects of this stimulus would not be expected until October, and what happened during the summer and fall of 2006 would be determined in part by the stance of the Fed prior to June. The index proposed in (19) offers one convenient tool for summarizing the combined consequences of current easing with previous tightening. The subsequent values for this index, plotted in the left half of Figure 10, show that, even though the Fed surprised the market with a more expansionary stance beginning July 13, the cumulative implications of that posture combined with previous tightening in fact became increasingly contractionary through August 23, reflecting the delayed effect of the unanticipated contraction prior to June 30. The cumulative consequences started to become slightly less contractionary subsequent to August 23, with the turning point reached on October 12, 2006, after which the net Fed contribution was one of stimulus rather than contraction.

A calculation that is easy to perform is to project the index (19) forward under the assumption that there are no subsequent surprises in monetary policy, i.e., by setting future values of $\ell(d)$ and $s(d)$ to zero. The resulting series is displayed in the right half of Figure 10. This reveals that the effects of previous monetary policy would have been expected to grow increasingly expansionary through the end of November.

5 Conclusions.

The current mortgage rate reflects a rational anticipation of all future Fed policy actions. In order to change the mortgage rate, the Fed must do something other than what the market anticipated, and any change in Fed policy seems to show up in mortgage rates as soon as the market anticipates it. An unanticipated 10-basis-point increase in the level of the term structure of near-term expected fed funds rates raises the mortgage rate by 5 basis points. An unanticipated 10-basis-point increase in the slope raises the mortgage rate by 13 basis points.

The consequences of such changes do not have their peak effect on new home sales until 15 weeks after mortgage rates go up. This delay might be attributed to heterogeneity across households in the time required to learn about changes in mortgage rates and to buy a new home. These dynamic relations, which have been directly estimated in detail here using daily and weekly time-series data, are claimed to account for some of the long lags found in more traditional analysis using time-aggregated monthly data. The framework also enables us to summarize on a daily or even minute-by-minute basis, if desired, the cumulative consequences of recent innovations in Fed policy or hypothetical future scenario as of any particular historical moment.

Appendix

This appendix derives the approximate martingale property for a long-term bond sampled at high frequencies.

Consider a mortgage that is acquired on day d and requires the household to make a fixed nominal payment $A(d)$ on the first day of each month for the next 30 years (or for $M^* = 360$ months). If $V(d)$ denotes the total amount borrowed on day d, then for the pricing kernel $\lambda_s(d)$ relating a payment made on the first day of the sth following month to the present day d,

$$V(d) = \sum_{s=1}^{M^*} E_d[\lambda_s(d)]A(d). \tag{20}$$

The terms of such a loan are often quoted in terms of the fixed mortgage interest rate $R(d)$ that satisfies

$$V(d) = v_d[R(d)]A(d) \tag{21}$$

for $v_d(R)$ a known function.[15] Equating (20) with (21) gives

$$v_d[R(d)] = \sum_{s=1}^{M^*} E_d\lambda_s(d). \tag{22}$$

If the previous day falls within the same month ($m^*(d) = m^*(d-1)$), then

$$v_{d-1}[R(d-1)] = \sum_{s=1}^{M^*} E_{d-1}\lambda_s(d-1) = \sum_{s=1}^{M^*} E_{d-1}q(d)\lambda_s(d) \tag{23}$$

[15] Specifically, if $R(d)$ is quoted at an annual rate (as a fraction of unity) and the loan is compounded monthly,

$$v_d[R(d)] = \left[1 + \left(\frac{d^\dagger[m^*(d)] - d + 1}{365}\right) R(d)\right]^{-1} \sum_{s=1}^{M^*} \frac{1}{\{1 + [R(d)/12]\}^{s-1}}.$$

where $q(d)$ denotes the one-day discount factor, e.g.,

$$q(d) = \frac{\beta U'(c(d))/P(d)}{U'(c(d-1))/P(d-1)} \simeq 1.$$

If uncertainty about the one-day discount factor relating today with tomorrow is negligible as of day $d-1$, then (23) implies

$$v_{d-1}[R(d-1)] \simeq [E_{d-1}q(d)] \sum_{s=1}^{M^*} E_{d-1}\lambda_s(d). \tag{24}$$

Furthermore, the function $v_{d-1}(R)$ differs from $v_d(R)$ by one-day's discounting, so approximately

$$v_{d-1}(R) \simeq [E_{d-1}q(d)]v_d(R). \tag{25}$$

Equations (24) and (25) imply

$$v_d[R(d-1)] \simeq \sum_{s=1}^{M^*} E_{d-1}\lambda_s(d). \tag{26}$$

Subtracting (26) from (22),

$$v_d(R(d)) - v_d(R(d-1)) \simeq \sum_{s=1}^{M^*}(E_d - E_{d-1})\lambda_s(d). \tag{27}$$

If we approximated $v_d(R)$ with a linear function ($v_d(R) \simeq v_0 + v_1 R$), then (27) implies that daily changes in the quoted mortgage rate $R(d)$ should be very difficult to forecast, reflecting primarily new information about the discount factor relevant for the next 30 years:

$$R(d) - R(d-1) \simeq v_1^{-1} \sum_{s=1}^{M^*}(E_d - E_{d-1})\lambda_s(d).$$

The above argument exploited the fact that, as one moves from day $d-1$ to day d, the days on which payment is made (the first day of each of the following months) remain fixed.

If one evaluates the expression on the last day of a month, there is an added difference in that one drops the near-term payment and adds another at the very end. Again if the term of the mortgage is very long and discount rates are stationary, this adjustment should make only a modest difference in the calculation.

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Table 1

Tests of null hypothesis that indicated variables are of no use in predicting weekly changes in mortgage rate

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***F* tests**

Variables	*F* statistic	*p* value
More weekly lags $\{\Delta R_{w-j}\}_{j=4}^{6}$	$F(3,915) = 0.02$	0.997
Monthly lags $\{\tilde{R}_{m^*(w)-j} - \tilde{R}_{m^*(w)-j-1}\}_{j=1}^{6}$	$F(6,912) = 0.48$	0.82

***t* tests**

Variable	coefficient	(standard error)	*p* value
10-year minus 5-year Treasury yield	0.005	(0.009)	0.60
5-year minus 2-year Treasury yield	-0.004	(0.006)	0.51
2-year minus 1-year Treasury yield	-0.016	(0.012)	0.18
1-year minus 6-month Treasury yield	-0.018	(0.019)	0.36
Baa minus 10-year Treasury yield	0.001	(0.006)	0.85
12-month job growth as currently reported for period ending previous month	0.26	(0.25)	0.29
12-month job growth as reported at the time for most recent period	0.21	(0.27)	0.44

Notes. All entries refer to *t* or *F* test of the null hypothesis that the coefficient vector γ is zero in the regression

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \gamma' x_w + \varepsilon_w$$

for x_w the indicated variable or variables. In row 2, $m^*(w)$ refers to the month in which week *w* occurs and $\tilde{R}_{m^*(w)}$ to the average value for R_w across all the weeks of the month in which week *w* occurs. Note that $\tilde{R}_m$ is identical to the monthly mortgage series reported by the FRED database of the Federal Reserve Bank of St. Louis.

Table 2

Coefficients relating change in mortgage rate to innovation in level or slope

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Regression description	**Explanatory variable**	**----Effects of level----**		**----Effects of slope----**	
		Symbol	**Coefficient (std error)**	**Symbol**	**Coefficient (std error)**
weekly change ΔR_w on each day's innovation					
(1)	1st day of week	ℓ_{w8}	0.43	s_{w8}	1.16
			(0.12)		(0.22)
(2)	2nd day of week	ℓ_{w7}	0.59	s_{w7}	1.06
			(0.13)		(0.23)
(3)	3rd day of week	ℓ_{w6}	0.65	s_{w6}	1.37
			(0.08)		(0.18)
(4)	4th day of week	ℓ_{w5}	0.70	s_{w5}	1.56
			(0.11)		(0.20)
(5)	5th day of week	ℓ_{w4}	0.21	s_{w4}	1.14
			(0.10)		(0.20)
weekly change ΔR_w on sum of innovations for all 5 days of week					
(6)		$\ell_{w4} + \ldots + \ell_{w8}$	0.53	$s_{w4} + \ldots + s_{w8}$	1.33
			(0.04)		(0.10)
change in last 4 weeks of month $(\tilde{R}_{m1} - \tilde{R}_{m5})$ on each week's cumulative innovations					
(7)	last week of month	$\tilde{\ell}_{m1}$	0.14	$\tilde{s}_{m1}$	1.07
			(0.22)		(0.44)
(8)	week before that	$\tilde{\ell}_{m2}$	0.64	$\tilde{s}_{m2}$	1.35
			(0.18)		(0.43)
(9)	week before that	$\tilde{\ell}_{m3}$	0.30	$\tilde{s}_{m3}$	1.96
			(0.16)		(0.42)
(10)	week before that	$\tilde{\ell}_{m4}$	0.40	$\tilde{s}_{m4}$	1.64
			(0.20)		(0.39)

change in last 4 weeks of month $(\tilde{R}_{m1} - \tilde{R}_{m5})$ on sum of 4 weeks' cumulative innovations

(11)		$\tilde{\ell}_{m1} + ... + \tilde{\ell}_{m4}$	0.41	$\tilde{s}_{m1} + ... + \tilde{s}_{m4}$	1.53
			(0.09)		(0.18)

weekly change ΔR_w on innovations for only monetary policy announcement days

(12)	1st day of week	$a_{w8}^{[MP]}\ell_{w8}$	0.19	$a_{w8}^{[MP]}s_{w8}$	1.31
			(0.28)		(0.54)
(13)	2nd day of week	$a_{w7}^{[MP]}\ell_{w7}$	1.59	$a_{w7}^{[MP]}s_{w7}$	1.93
			(0.86)		(8.11)
(14)	3rd day of week	$a_{w6}^{[MP]}\ell_{w6}$	0.76	$a_{w6}^{[MP]}s_{w6}$	0.79
			(0.23)		(1.30)
(15)	4th day of week	$a_{w5}^{[MP]}\ell_{w5}$	0.36	$a_{w5}^{[MP]}s_{w5}$	3.53
			(0.26)		(2.45)
(16)	5th day of week	$a_{w4}^{[MP]}\ell_{w4}$	0.47	$a_{w4}^{[MP]}s_{w4}$	1.05
			(0.21)		(0.93)

weekly change ΔR_w on sum of innovations for only monetary policy announcement days

(17)		$a_{w4}^{[MP]}\ell_{w4} + \cdots + a_{w8}^{[MP]}\ell_{w8}$	0.53	$a_{w4}^{[MP]}s_{w4} + \cdots + a_{w8}^{[MP]}s_{w8}$	1.49
			(0.11)		(0.39)

Table 3

Coefficients relating weekly change in mortgage rates to change in level and slope on the day that news of the indicated type is released, along with F tests of the null hypothesis that these coefficients are the same as those for all other days

News release (q)	level $\hat{\theta}_1^{[q]}$	slope $\hat{\theta}_2^{[q]}$	F test	p value
(1) Capacity utilization	0.46	1.54	0.01	0.99
	(0.25)	(0.59)		
(2) Unemployment	0.84	1.54	1.80	0.17
	(0.12)	(0.31)		
(3) Consumer price index	0.83	1.59	1.61	0.20
	(0.27)	(0.54)		
(4) Consumer confidence	0.14	0.29	0.94	0.39
	(0.39)	(0.57)		

Notes. Coefficients $\hat{\theta}_1^{[q]}$ and $\hat{\theta}_2^{[q]}$ (with OLS standard errors in parentheses) are based on the regression

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \theta_1^{[q]} \sum_{j=4}^{8} a_{wj}^{[q]} \ell_{wj} + \theta_2^{[q]} \sum_{j=4}^{8} a_{wj}^{[q]} s_{wj} + \varepsilon_w$$

where $a_{wj}^{[q]} = 1$ if news of type q is released on day j of week w and is zero otherwise. F test is the $F(2{,}906)$ statistic for testing the null hypothesis that $\lambda_1^{[q]} = \lambda_2^{[q]} = 0$ in the regression

$$\Delta R_w = c + \sum_{j=1}^{3} \beta_{0j} \Delta R_{w-j} + \theta_1 \sum_{j=4}^{8} \ell_{wj} + \theta_2 \sum_{j=4}^{8} s_{wj} + \lambda_1^{[q]} \sum_{j=4}^{8} a_{wj}^{[q]} \ell_{wj} + \lambda_2^{[q]} \sum_{j=4}^{8} a_{wj}^{[q]} s_{wj} + \varepsilon_w.$$

Table 4

Coefficients from regression of 100 times the log of seasonally unadjusted new home sales on 30 weekly lags of mortgage rate changes and other explanatory variables; (standard errors in parentheses).

---

d_{m1}	January	46.0 (14.9)	h_{m-1}	1st lag home sales	0.48 (0.08)
d_{m2}	February	60.5 (14.9)	h_{m-2}	2nd lag home sales	0.15 (0.08)
d_{m3}	March	65.9 (15.2)	h_{m-3}	3rd lag home sales	0.14 (0.08)
d_{m4}	April	52.7 (15.5)	h_{m-4}	4th lag home sales	-0.10 (0.08)
d_{m5}	May	53.2 (15.7)	h_{m-5}	5th lag home sales	0.17 (0.07)
d_{m6}	June	49.7 (15.9)	m	time trend	0.073 (0.023)
d_{m7}	July	46.2 (16.0)	y_m	previous GDP growth	2.63 (1.02)
d_{m8}	August	46.4 (15.9)			
d_{m9}	September	34.2 (15.8)			
$d_{m,10}$	October	39.9 (15.6)			
$d_{m,11}$	November	32.4 (15.5)			
$d_{m,12}$	December	34.7 (15.2)			

Table 5

Estimates of search distribution parameters from alternative sources.

---

(1) Maximum likelihood estimation of cross-section distribution of reported time to search before buying new home.

	coefficient	standard error
k_W shape	0.972	(0.014)
λ_W scale	14.70	(0.276)
mean lag	14.9 weeks	

(2) Maximum likelihood estimation of relation between new home sales and 30 most recent weekly changes in mortgage rates.

	coefficient	standard error
k_W shape	3.24	(0.63)
λ_W scale	14.97	(1.01)
α_W mortgage effect	-0.20	(0.036)
mean lag	13.4 weeks	

(3) Maximum likelihood estimation of relation between new home sales and 125 most recent daily changes in level and slope of fed funds futures.

	predicted value	MLE	standard error
k_D shape	3.24	2.74	(1.02)
λ_D scale	71.85	47.94	(8.39)
α_L level effect	-0.10	-0.01	(0.06)
α_S slope effect	-0.26	-0.39	(0.14)
mean lag	64.4 days	42.6 days	

Table 6

2SLS estimation of effects of mortgage rate on new home sales using fed-funds-based measures as instruments

mortgage measure	instruments	$\hat{\alpha}_{2SLS}$ (std err)	J stat (p value)	DWH (p value)	OLS F (p value)
			$\chi^2(30)$	$F(30,130)$	$F(60,100)$
(1) unrestricted	all weekly innovations	-----	28.86 (0.53)	1.07 (0.38)	1.39 (0.07)
			$\chi^2(59)$	$F(1,188)$	$F(60,129)$
(2) restricted	all weekly innovations	-0.19 (0.05)	74.14 (0.09)	0.19 (0.66)	1.40 (0.06)
			$\chi^2(59)$	$F(1,188)$	$F(60,129)$
(3) restricted	policy days only	-0.27 (0.07)	65.89 (0.25)	1.37 (0.24)	1.22 (0.17)

Figure 1. Response of industrial production (in percentage annual growth rate) to 25-basis-point increase in fed funds rate for different Cholesky orderings.

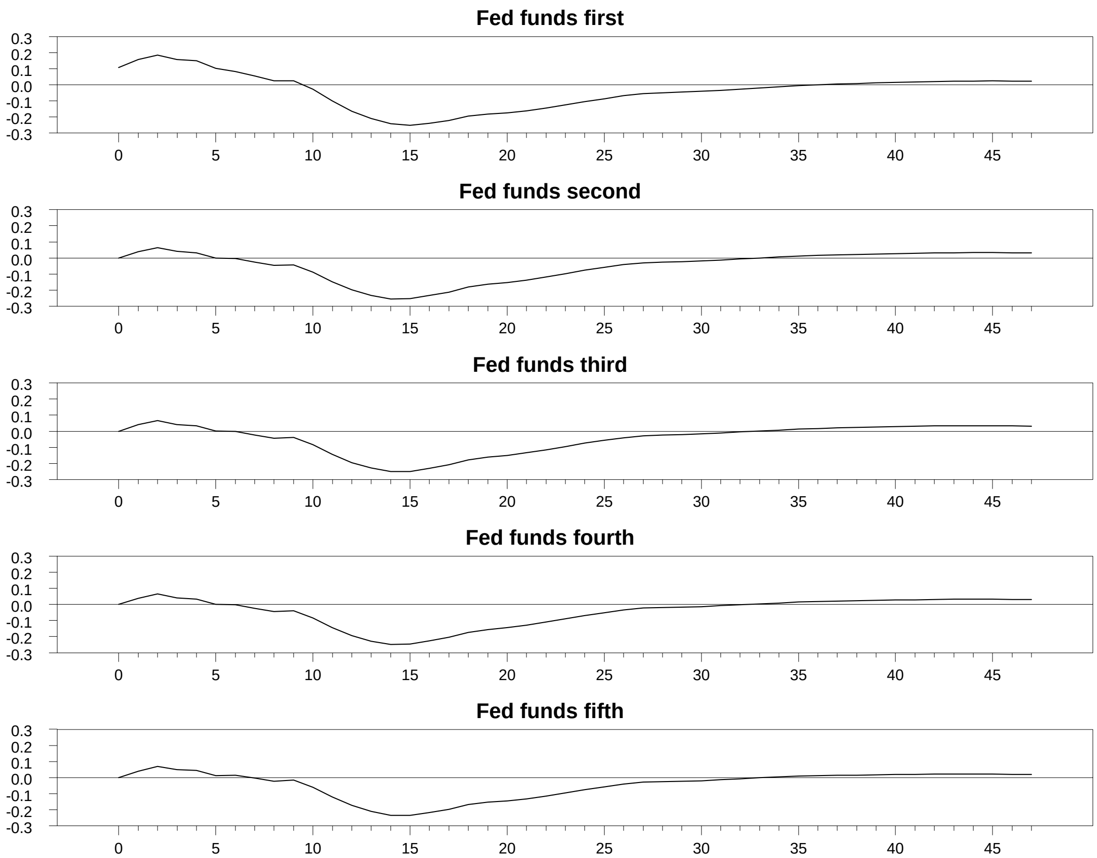

Figure 2. Forecast errors for predicting (1) fed funds using lagged variables and all other current variables in the VAR, (2) fed funds using the previous months' 1-month futures contract, and (3) the 2-month-ahead futures rate using the previous months' 3-month-ahead futures rate.

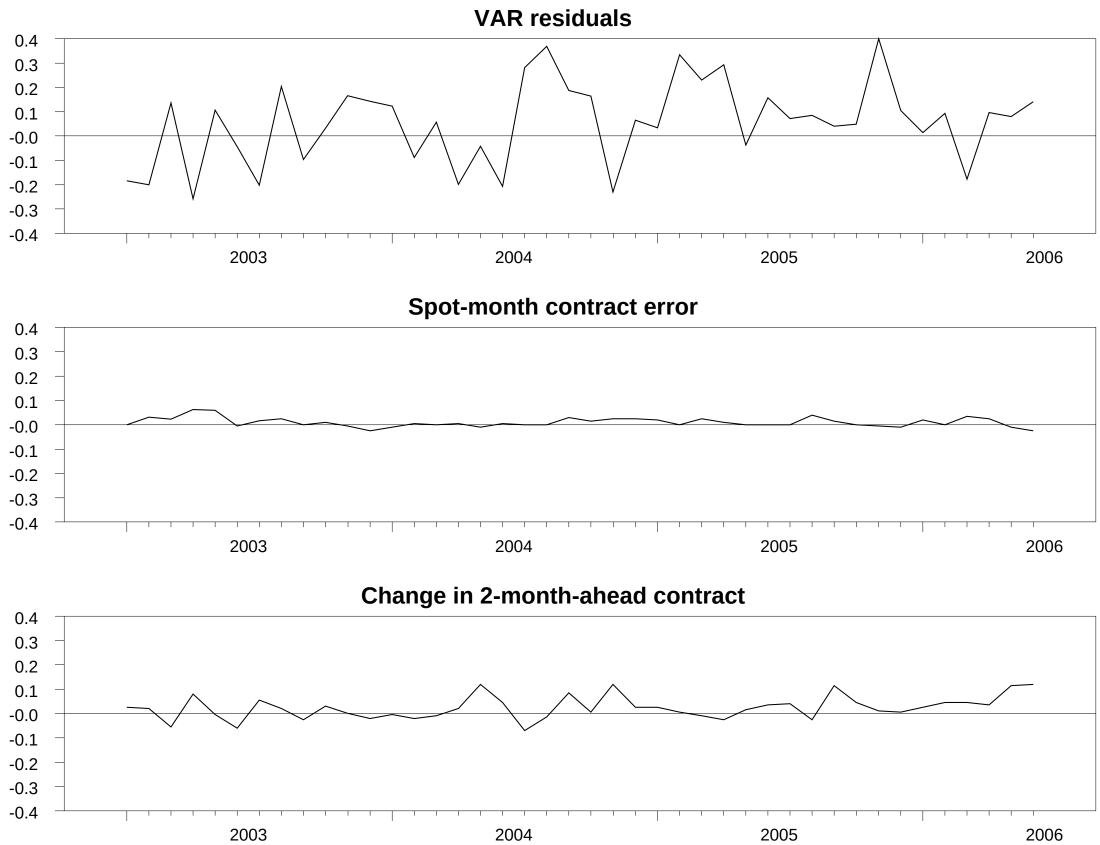

Figure 3. OLS coefficients and 95% confidence intervals for each day's level, slope and curvature from regressions of ΔR_w on a constant, three of its own lagged values, and level, slope and curvature for preceding 13 days.

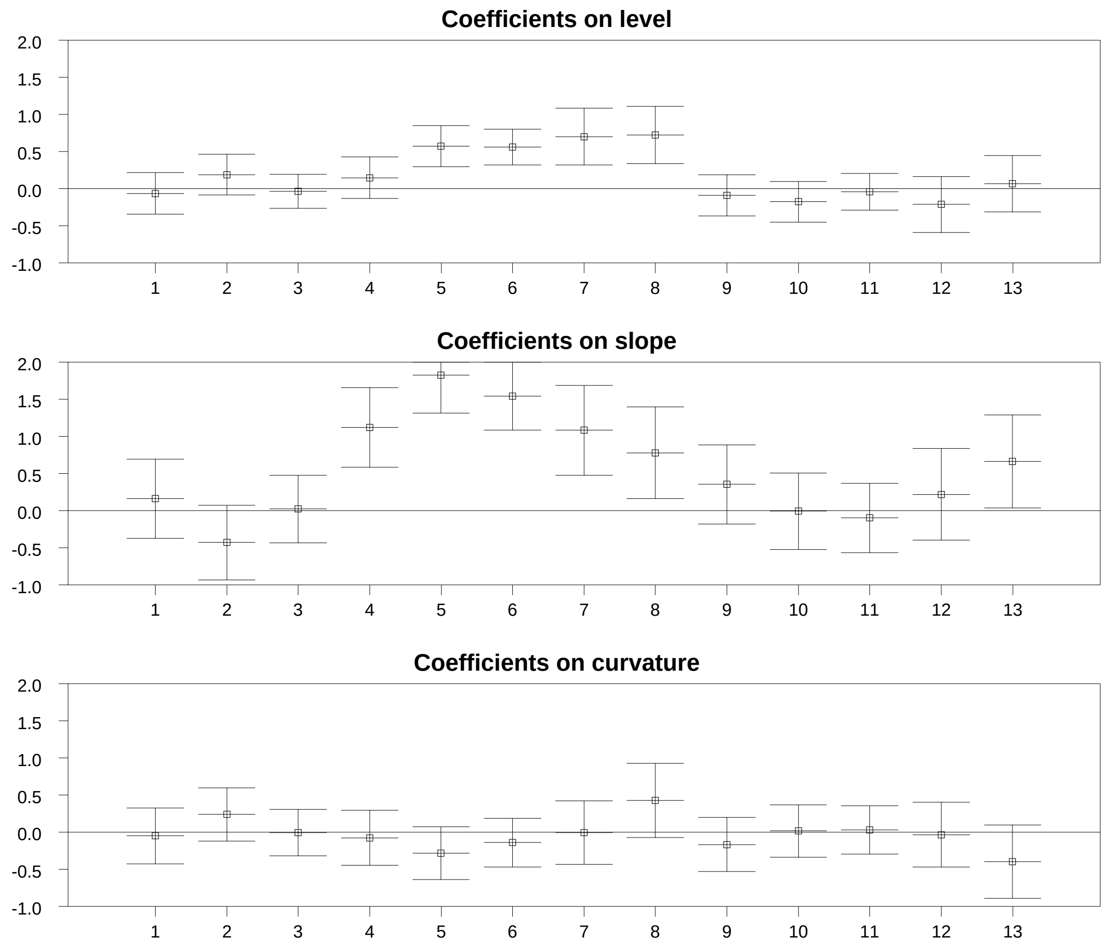

Figure 4. Coefficients and 95% confidence intervals relating monthly home sales to mortgage changes at indicated lags.

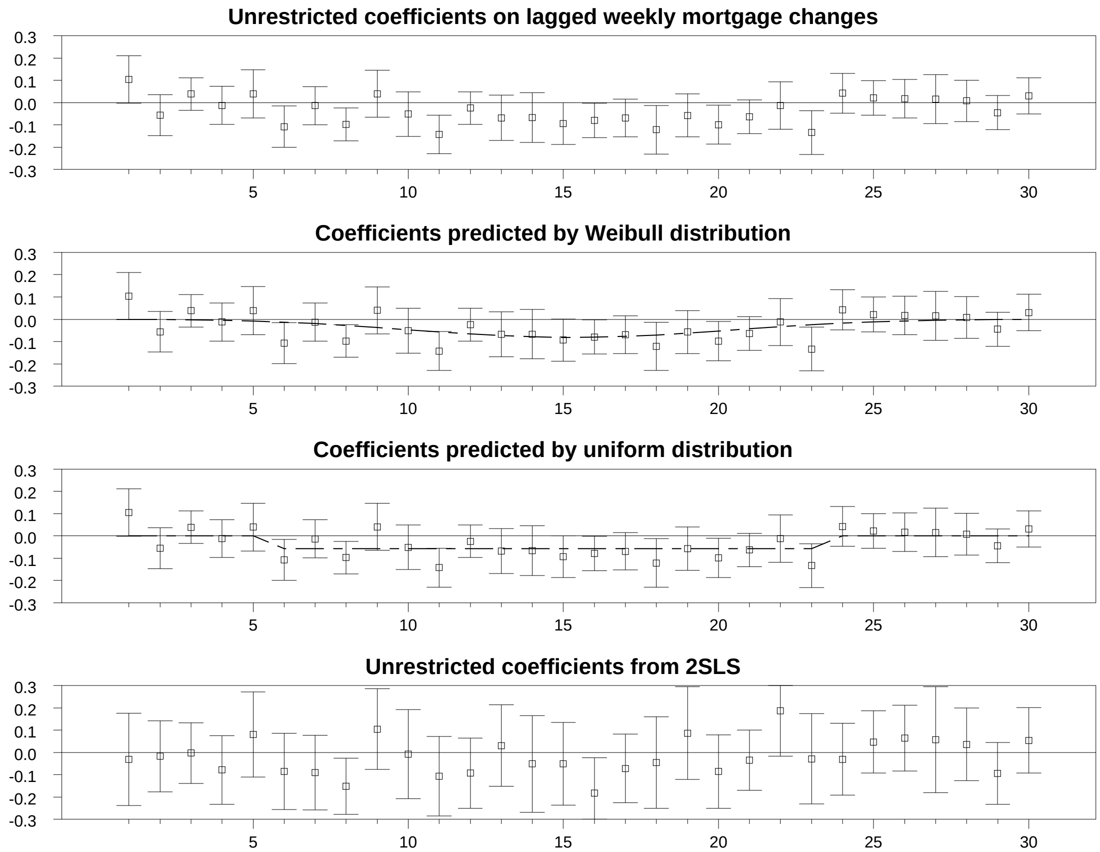

Figure 5. Top panel: sample histogram and MLE density-estimate based on cross-section distribution of time required (in weeks) to purchase a home based on National Association of Realtors' 2005 Profile of Home Buyers and Sellers. Second panel: density from top panel alone. Third panel: density implied by Weibull parameters fit to time-series relation between new home sales and lagged weekly changes in mortgage rates. Fourth panel: density implied by Weibull parameters fit to time-series relation between new home sales and lagged daily changes in fed funds level and slope.

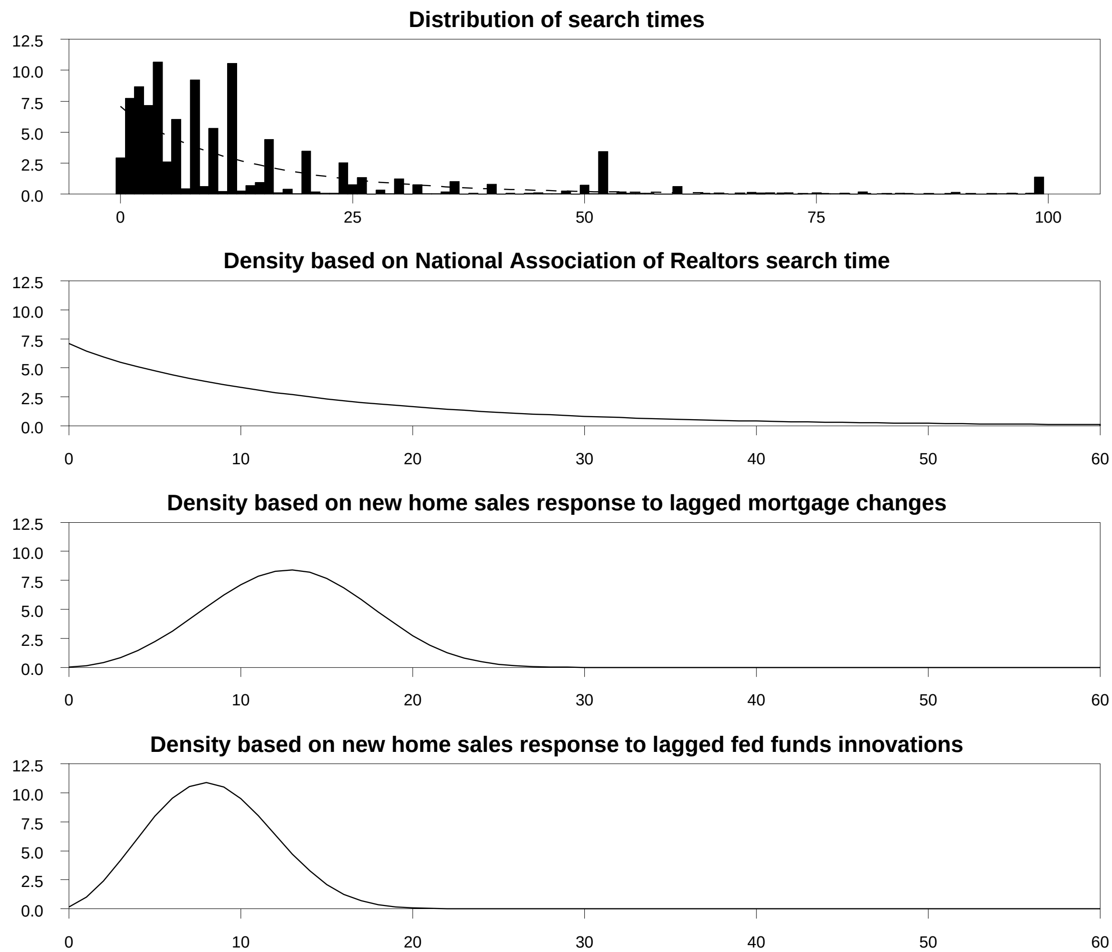

Figure 6. Average impulse-response function relating 10-basis-point increase in mortgage rate to 100 times the natural log of new home sales.

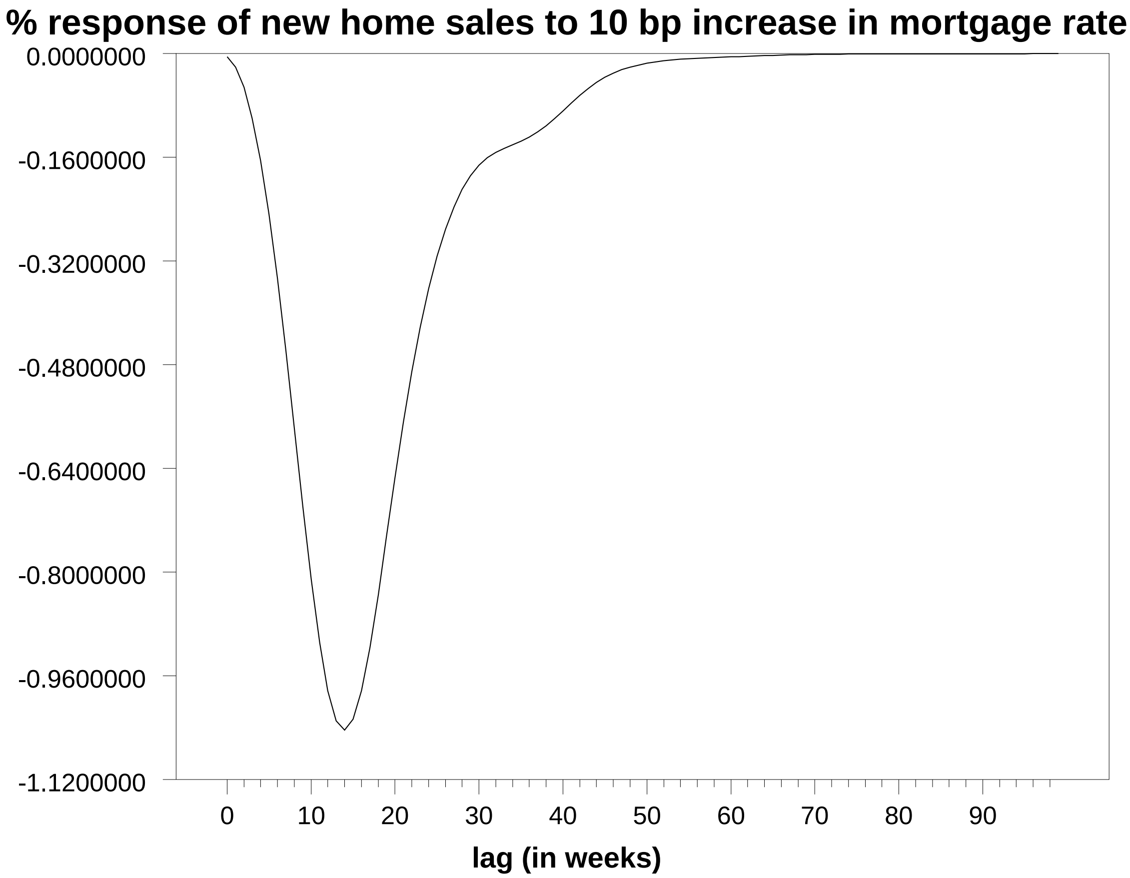

Figure 7. Index summarizing the consequences for new home sales on day *d* (the variable on the horizontal axis) of the history of monetary policy innovations prior to and including day *d* as calculated from equation (14).

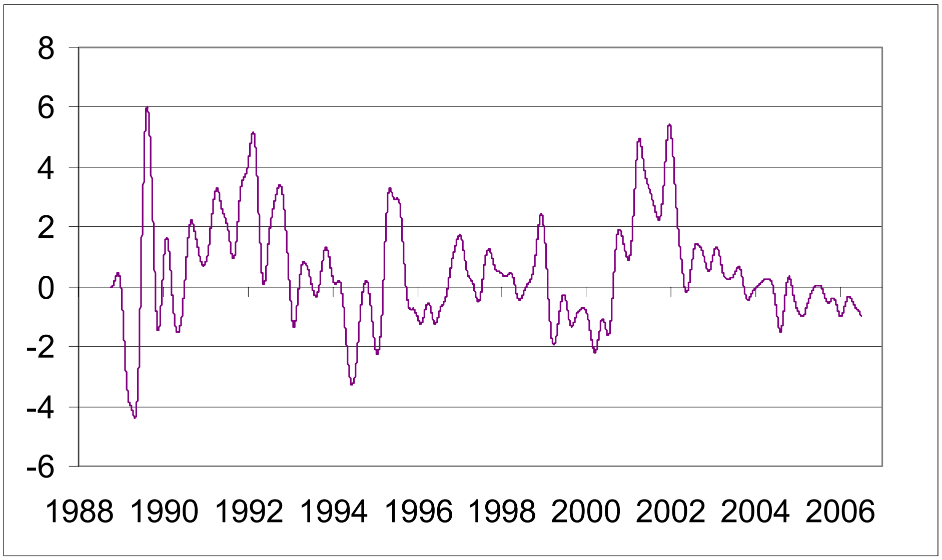

Figure 8. Values for the fed funds rate for October (solid line), September (short-dashed line), and August (long-dashed line) 2006 as implied by fed funds futures contracts traded July to October.

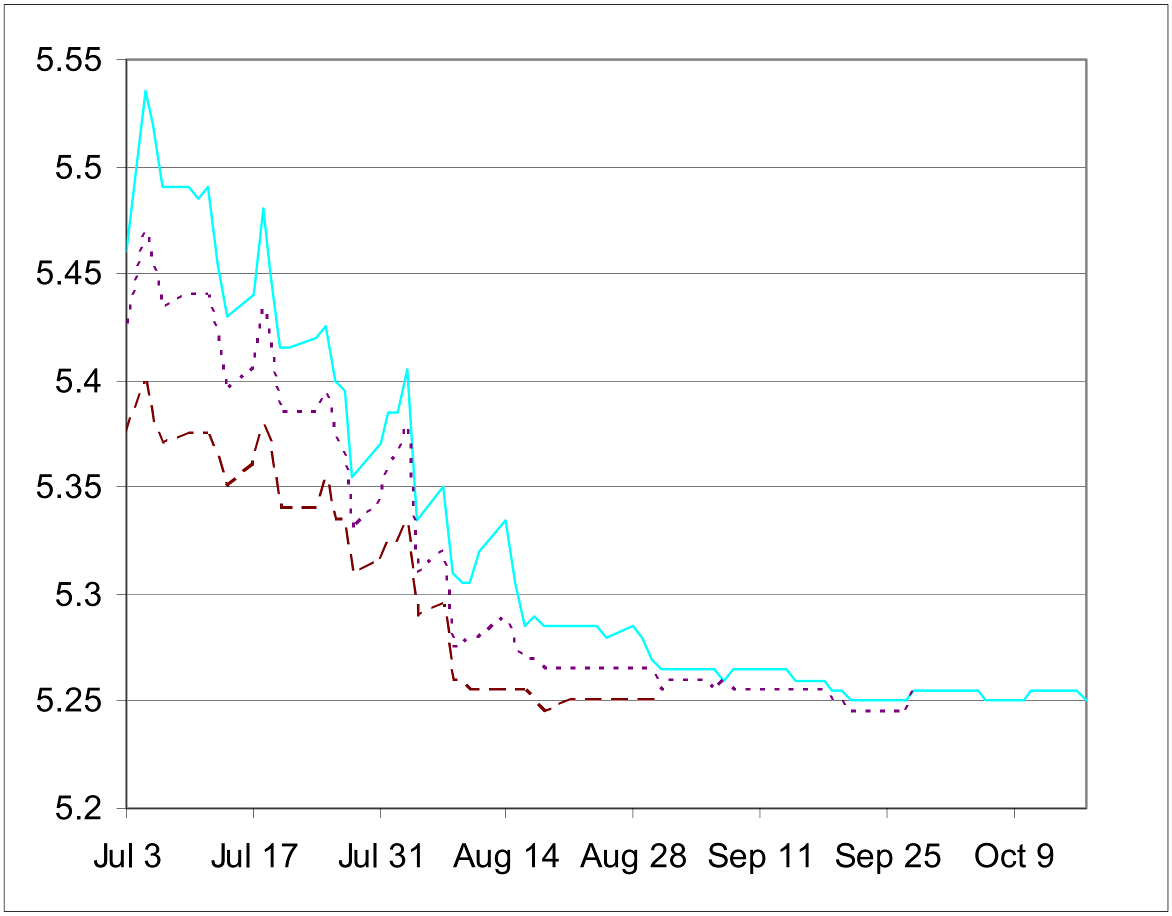

Figure 9. Cumulative change (in basis points) in weekly mortgage rate between July 3, 2006 and indicated date (dashed line) and cumulative change as predicted (solid line) by changes in level and slope of near-term fed funds futures.

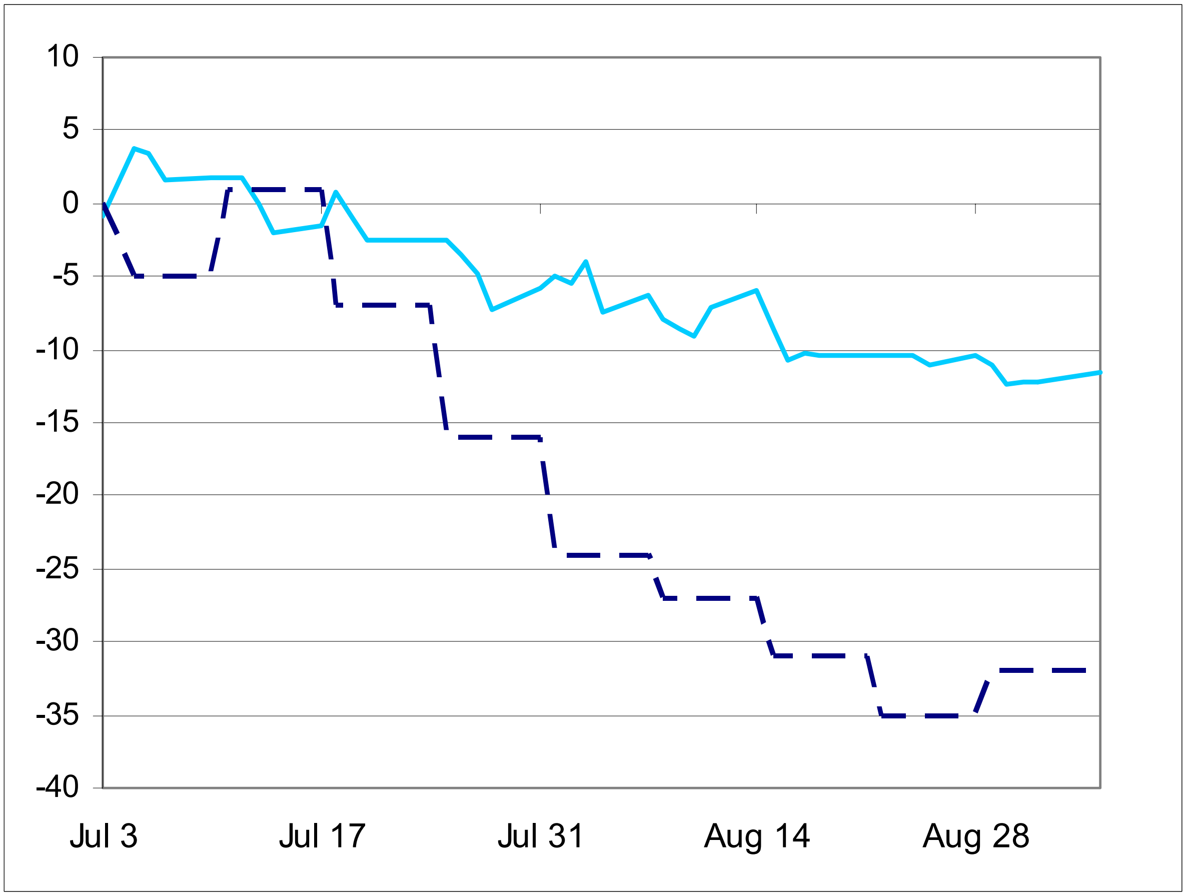

Figure 10. Solid line: index summarizing cumulative consequences of monetary policy through day *d* on new home sales for day *d*; dashed line: index summarizing cumulative consequences of monetary policy through October 16 on new home sales for day *d*.