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Bernanke vs. Taylor: A Post Mortem
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James S. Fackler
University of Kentucky

W. Douglas McMillin
Louisiana State University

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Department of Economics
Louisiana State University
Baton Rouge, LA 70803-6306
http://www.bus.lsu.edu/economics/

Bernanke vs. Taylor: A Post Mortem

James S. Fackler
Department of Economics
University of Kentucky
Lexington, KY 40506
jamesfackler@gmail.com

W. Douglas McMillin
Department of Economics
Louisiana State University
Baton Rouge, LA 70803-6306
eodoug@lsu.edu

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Abstract

Our analysis is intended to shed light on the issue of whether monetary policy contributed to the recent housing boom and bust. We have estimated and analyzed a model that allows a comparison between actual policy and several alternative Taylor Rules. When the Taylor Rule path was computed using revised data and the GDP deflator, we found a notable impact on key housing market variables, supporting Taylor's critique of Fed policy. However the bulk of our evidence suggests that policy as it would have been conducted under our real-time Taylor Rules would not have had any significant impact on the housing market variables. This conclusion is robust with regard to the price index used as well as the relative weights used on the inflation and output gaps.

1. Introduction

Did Federal Reserve policy during the last decade cause, or at least prolong, the boom and deepen the subsequent bust in house prices? Much of the discussion on this policy question has occurred in the context of the long-standing debate over policy rules versus discretion.

John Taylor (2012) argues that, in contrast to discretionary policies in the 1960s and ‘70s, over much of the 1980s and ‘90s price stability became the focus of a predictable rules-based policy which led to lower and less volatile inflation and interest rates, a reduction in the volatility of output, a decrease in the unemployment rate, longer-lived and stronger expansions, and shorter and less-severe recessions. However, he contended that, in a move away from rules-based policy that began in 2003 and continued through 2005, interest rates were held too low for too long which led to excessive risk taking and stimulated the housing boom.

Ben Bernanke (2010) argues that the low federal funds interest rate target set by the Fed after 2002 reflected the slow recovery from the recession that ended in 2001 and a concern that deflation might emerge. In his 2012 lecture, he contends that Fed policy was not the cause of the boom in home prices. Specifically, he noted that “... the evidence I’ve seen suggests that monetary policy did not play an important role in raising house prices during the upswing.” He supports this statement in part by noting that other countries experienced their own housing booms with different policies in place, that the U.S. housing price acceleration began prior to the low interest rates pursued by the Fed beginning in 2003, and that house prices continued to rise after the Fed started to raise rates later in the decade.

In order to evaluate whether monetary policy was too expansionary for too long from the early to mid-2000s, a benchmark is needed. Although there are a variety of policy rules that could be used as the benchmark (see, for example, the introduction to, and papers in, Taylor (1999)), Asso, Kahn, and Leeson (2010) note the widespread use of Taylor Rules in macro models and document the use of Taylor Rules as benchmarks for Federal Reserve policymakers in evaluating current policy and in thinking about the future path of the federal funds rate. Consequently, in this paper we consider Taylor Rules as the monetary policy benchmarks. Since Taylor (2012) used the value of the federal funds rate from the original Taylor Rule formulation (Taylor, 1993) with revised (as opposed to real-time) data as the metric for judging the appropriateness of monetary policy,[1] we mostly focus on the original specification of the Taylor Rule with equal weights of 0.5 on the deviation of inflation from target and the output gap. Using these weights, the discussion in the text centers on two alternatives for the price index. First, we employ the GDP revised deflator as the price index used in the rule, Taylor's original specification. Second, we construct a real-time Taylor Rule using the index for personal consumption expenditures, consistent with the index currently employed by the Fed in conducting policy. As a check on the robustness of our results, among several alternatives, we discuss at the end of the paper a variant discussed by Taylor (1999) and preferred by Yellen (2012) in which the weight on the output gap is increased to 1.0 while maintaining the weight on the inflation gap at 0.5.[2]

As can be seen in Figure 1 below, beginning in mid-2001, the actual federal funds rate target is persistently below the value prescribed by the original Taylor Rule that uses revised data for the year-over-year rate of change in the GDP deflator (FFR_TARGET vs. TR_REVISED_GDPD in the top panel) and the year-over-year rate of change in the core PCE deflator (FFR_TARGET vs. TR_REVISED_PCEX in the bottom panel). Both revised-data Taylor Rule variants are constructed using the percentage deviations of real GDP from the CBO estimate of potential GDP. Compared with the actual target, the differential for the Taylor Rule target series using the revised GDP deflator peaks near 400 basis points in mid-2004, and the actual target path persisted below the Taylor Rule value until mid-2007; the differential for the revised target series using the core PCE deflator peaks near 300 basis points and the actual target funds rate persisted below this variant of the Taylor Rule until early 2006. The mean absolute deviation of

[1] The original Taylor Rule formulation is $ffr_t = 2.0 + \pi_t + 0.5(\pi_t - 2.0) + 0.5\,ygap_t$ where ffr_t = federal funds rate in period t, the intercept 2.0 is an estimate of the long-run equilibrium real federal funds rate, π_t is the year-over-year inflation rate (measured by the GDP deflator in Taylor (1993)) with $(\pi_t - 2.0)$ the current period deviation of inflation from an assumed target rate of 2%, $ygap_t$ is the output gap in period t, and 0.5 are weights on the deviations of inflation from target and the output gap.

[2] Although this paper examines the effects of monetary policy on housing prices, the important and controversial question of how, or even whether, monetary policy should respond to asset prices is beyond the scope of the paper.

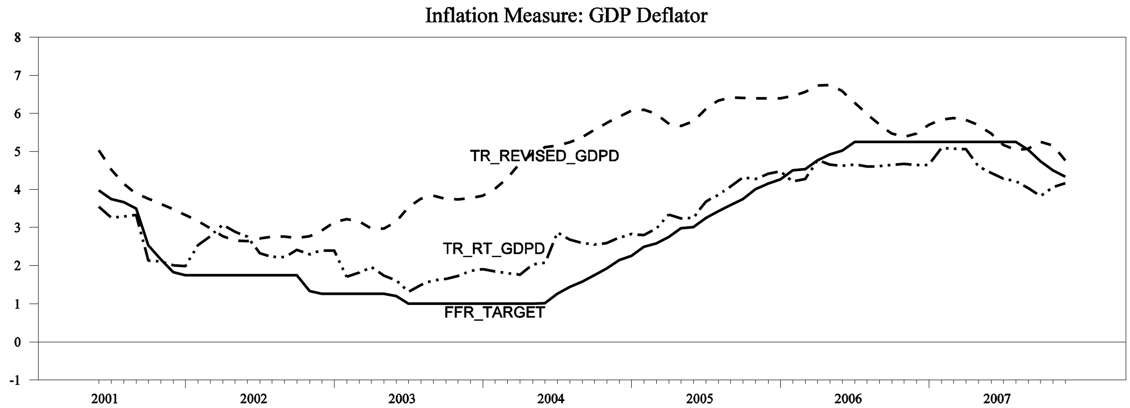
the revised GDP deflator measure from the target funds rate is 1.85 and for the revised core PCE measure is 1.21.

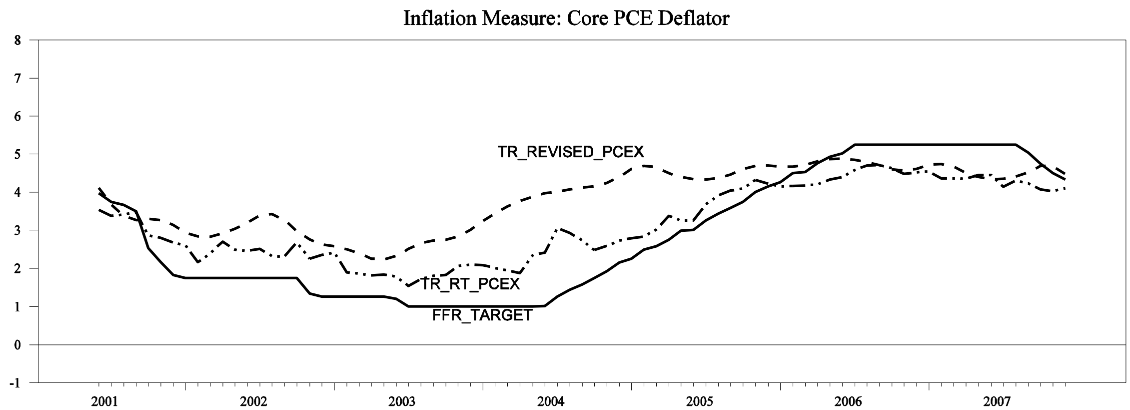
However, as noted by Bernanke (2010), monetary policy decisions in real time are made using forecasts, and forecasts for inflation or the output gap for a given time period can differ substantially from subsequently-revised measures of these variables. Consequently, the value of the federal funds rate from a Taylor Rule computed using real-time data is arguably better for evaluating the appropriateness of monetary policy than are values computed using subsequently-revised data. Furthermore, given that the Federal Reserve is forward-looking in its monetary policy decisions, values of the federal funds rate for the original Taylor Rule specification but computed using the average of the current and three-period-ahead Greenbook forecasts of inflation and the output gap are also plotted in Figure 1.[3] It is evident that the real-time Taylor Rule values are much closer to the actual target values chosen by the Fed; the mean absolute deviation from the target funds rate of the real-time rule using the GDP deflator is 0.60 (about one-third of that for the revised data) and for the core PCE measure is 0.69 (about fifty-seven percent of that for the revised data). We also note that both of these real-time Taylor Rule values are above the actual target funds rate until late 2005 for both inflation measures, but the real-time Taylor Rule values fall below the actual target funds for both inflation measures in mid-2005.

The issue in the debate about policy in the last decade is whether this sustained federal funds rate policy path, depicted by FFR_TARGET in both panels of Figure 1, below the Taylor Rule path(s) was a significant factor in the housing price boom and subsequent bust. Furthermore, it may be the case that the outcome of the debate turns on which Taylor Rule is viewed as relevant; both visually and in terms of mean absolute deviations, it appears that the target rate values from the rules using revised data are notably higher than for the rules constructed with real-time data. Thus, the conclusion reached on whether the Fed's deviation from (some) Taylor Rule can be implicated in the housing market boom and bust may depend on one's view of the plausibility of the alternative Taylor Rules themselves.

[3] Details of the construction of the real-time Taylor Rule values of the federal funds rate are provided in section 4.

Figure 1: Taylor Rule Values vs. Federal Funds Rate Target





Taylor (2007) argues that the standard approach to analyze an issue such as this is to conduct a counterfactual analysis.[4] Several recent studies, including Del Negro and Otrok (2007), Jarocinski and Smets (2008), Bean et al. (2010), Luciani (forthcoming), Eickmeier and Hofmann (2013) and Dokko et al (2013), have employed counterfactual experiments in the context of VAR models to assess the effects of monetary policy on housing prices. These authors all considered the effects of relatively contractionary monetary policy compared with what was actually implemented over the period of the housing price rise, and hence provide general information about the effects of tighter monetary policy on house prices. However, with the exception of Luciani (forthcoming), the contractionary policies they considered were

[4]He assesses the effect of deviating from the Taylor Rule on the housing market using, first, a simple single equation model in which the fed funds rate affects housing starts. He later allows house prices as well as the fed funds rate to affect housing starts and models house prices with a simple single equation (whose specification is unstated). He reports that in both cases following the Taylor Rule would have restrained the housing boom by reducing the increase in housing starts over the 2003-2005, but he doesn't consider the impact on house prices.

not obviously tied to a Taylor Rule, so that it is unclear what benchmark comparison is employed. We also estimate a VAR and consider the effects of monetary policy on house prices. Our study differs from the earlier ones by performing counterfactual experiments that force the federal funds rate to follow, alternatively, the paths prescribed by the proposed Taylor Rules over the period from the middle of 2001 to the end of 2007. Unlike Luciani (forthcoming) who considers only Taylor Rule values constructed using revised data, we also consider Taylor Rule values constructed using real-time data. While there are clearly other monetary policy rules that could be investigated, Greenspan argued (2004, pp. 38-39) that "Indeed, rules that relate the setting of the federal funds rate to the deviations of output and inflation from their respective targets, in some configurations, do seem to capture the broad contours of what we did over the past decade and a half."[5] Thus, our counterfactual experiments assess the impact of monetary policy rules that at least approximately summarize the policy approach that had been followed immediately prior to the period of analysis.

We proceed as follows. In section 2, we briefly review the recent literature on the role played by monetary policy in the housing boom and bust. In section 3, we provide details on our empirical model. In section 4, we briefly present our counterfactual methodology with which we will assess the paths and standard error bounds key variables would have followed if monetary policy had adhered to given specifications of the Taylor Rule; technical presentation of the methodology is included in the appendix. In section 5 we present the results of our counterfactual experiments. In section 6, we provide concluding comments.

2. Recent Literature

Although there are a number of studies that estimate the effects of monetary policy on the housing market (see, among others, Iacoviello (2005) and Vargas-Silva (2008)), there are relatively few that perform counterfactual experiments to try to estimate the contribution of monetary policy to the

[5] He continued later in the same paragraph: "But at crucial points, like those in our recent policy history (the stock market crash of 1987, the crises of 1997-1998, and the events that followed September 2001), simple rules will be inadequate as either descriptions or prescriptions for policy…"

housing market boom. These studies include Del Negro and Otrok (2007), Jarocinski and Smets (2008), Bean et al. (2010), Luciani (forthcoming), Eickmeier and Hofmann (2013), and Dokko et al (2013). We first summarize these studies and then explain how our study differs from them.

Del Negro and Otrok (2007) examine the effect of monetary policy on housing inflation and perform a counterfactual experiment designed to assess the contribution of monetary policy to the housing price boom. For the period 1986:1-2005:4, they estimate a Bayesian VAR model that includes the growth rates of a house price factor (the common component of state- or region-specific house price inflation), the CPI, real GDP, and differences of the federal funds rate and the 30-year mortgage rate. Monetary policy shocks are identified via sign restrictions, and impulse response functions indicate a significant, negative, transitory effect of a contractionary monetary policy shock on the house price factor. In their counterfactual experiment, they consider the effects of monetary policy shocks on the house price factor over the period 2001:1 to 2005:4 by setting the structural monetary policy shocks to zero while using the historical realizations of the other shocks. In essence, this approach views the federal funds rate equation as reflecting the endogenous forces affecting the policy rate plus the equation disturbance, with the latter reflecting policy innovations in which the Fed intervenes over and above the natural response of the funds rate to other system variables.[6] They compare the actual path of the federal funds rate with its counterfactual path and the actual path of the rate of change in the house price factor with its counterfactual path. Although they find that the counterfactual path of the federal funds rate generally lies above the actual path, with the deviation increasing in mid-2003, the counterfactual house price factor essentially coincides with the actual path of the house price factor. The largest deviation of their counterfactual fed funds rate from the actual fed funds rate is only about 80 basis points whereas, as seen above in our Figure 1, the largest deviation between the fed funds rate computed according to the original specification of the Taylor Rule using the revised GDP deflator and the actual fed funds rate is about 400

[6]This approach either assumes that there are no shocks to the federal funds rate other than the policy innovation or that policy can successfully offset them.

basis points. The maximum cumulative effect on the house price factor of the difference between the counterfactual path and the actual path of the house price factor is only about 1.3%.

Jarocinski and Smets (2008) use identified Bayesian VAR models estimated with quarterly data over the period 1987:1-2007:2 to analyze the effects of monetary policy on house prices. They estimate the models using both log levels and first differences. Their models include real GDP, real consumption, the GDP deflator, the ratio of real private residential investment to real GDP, real house prices, commodity prices, the fed funds rate, an interest rate term spread, and M2. They use a mixture of zero restrictions and sign restrictions to identify shocks to monetary policy, housing demand, and the term spread. Impulse response functions for both levels and first difference models indicate significant, negative, and long-lived but ultimately transitory movement in house prices and housing investment following a contractionary monetary policy shock. Counterfactual experiments for the 2000-2007 period are conducted by zeroing out the identified monetary policy shocks while employing the historical values of the other shocks and then comparing the counterfactual path with the actual path, essentially the same approach as Del Negro and Otrok. In the Jarocinski-Smets experiments, the largest deviation of the counterfactual path for the fed funds rate from the actual rate is over 100 basis points for the levels model and over 200 basis points for the differences model, both of which indicate a less expansionary monetary policy than actually followed. The counterfactuals for housing investment and house prices in both models indicate smaller increases in both housing investment and house prices than actually occurred, with bigger differences for the model estimated in first differences. They conclude that relatively loose monetary policy contributed to the boom in the housing market.

Bean et al. (2010) examine the effect of monetary policy shocks on, among other variables, real house prices using a Bayesian VAR estimated with quarterly data over the period 1966:3-2010:1. The VAR is estimated for both the U.S. and the U.K., but, given our focus on the U.S., only the results for the U.S. are discussed. The model for the U.S. comprises CPI inflation, GDP growth, a corporate-government bond yield spread, growth in real total private credit market debt outstanding, a macroeconomic volatility index, the rate of change in real house prices, and the federal funds rate.

Monetary policy shocks are identified using a Choleski decomposition with the federal funds rate ordered after all variables, except the house price variable which is ordered after the federal funds rate.[7] Impulse response functions indicate a significant, long-lived negative effect of monetary policy on the rate of change in house prices. An historical decomposition indicates that the actual federal funds rate averaged 1.5% points below the level suggested by the federal funds rate equation in the VAR over the 2002-2005 period and that monetary policy shocks generated an extra 1.5 percentage points real house price inflation over this period. Bean et al. (2010) also conduct a counterfactual experiment for the 2003-2006 period in which shocks to the federal funds rate were injected into the model that left the federal funds rate about 200 basis points higher than actual. In this counterfactual, the federal funds rate peaked around 7.5% in late 2006, and there was a significant reduction in real house price inflation beginning in 2004. The counterfactual suggests that tighter monetary policy would have led to a peak in house prices that was 7.5% lower than what was actually experienced.

Using a structural dynamic factor model estimated with quarterly data over the period 1982:3-2010:4 with monetary policy shocks identified using sign restrictions, Luciani (forthcoming) employs counterfactual simulations as well as a conditional forecasting exercise to examine the effects of monetary policy on the housing market and the overall economy for the period 2002:2-2006:3. Luciani's counterfactual is closest to what we do in this paper; however, he considers a counterfactual in which the federal funds rate follows the Taylor Rule path from Taylor (2007). This path was constructed using revised rather than real-time data. In his Taylor Rule counterfactual, Luciani finds that real house prices would have grown somewhat more slowly from 2002-2006, but the difference from actual growth was small. Residential investment would have grown more slowly and exhibited a bigger decline prior to the recession, but the maximum decline was about the same as the actual decline. Building permits exhibited a similar pattern to residential investment. Real GDP would have grown more slowly through 2007, but the size of the recession would have been about the same as actually experienced. His conditional forecasting exercise based on following the revised-data Taylor Rule path yielded similar results. Luciani

[7] Other shocks are identified using a blend of assumptions about contemporaneous ordering and sign restrictions.

concludes that, although following the Taylor Rule would have generated somewhat different outcomes in the housing market, especially for residential investment and building permits, following the rule would have made little difference in how the recession played out.

Eickmeier and Hofmann (2013) also perform a counterfactual analysis of the effects of monetary policy on the housing market. They estimate a factor-augmented VAR model using quarterly data over the period 1987:3-2007:4 and identify monetary policy shocks using a combination of the Choleski decomposition and sign restrictions. Their model includes real GDP growth, the inflation rate as measured by the rate of change in the GDP deflator, the federal funds rate, and six common factors derived from over two-hundred financial variables which include a number of housing market variables. In one counterfactual they consider the path of the federal funds rate that would have prevailed if there had been no financial shocks, and in a second they consider the funds rate that would have prevailed in the absence of both financial and macro shocks. They compute historical decompositions for the original monetary policy shocks and, in turn, for the shocks that would have been required to move the federal funds rate to both counterfactual measures. The difference between the historical decompositions for the original shocks and the counterfactual shocks represents, respectively, the contribution of the systematic response of monetary policy to financial shocks and the contribution of the systematic response of monetary policy to both financial shocks and macro shocks. Eickmeier and Hofmann compare the contribution to the path of house prices, household debt, and the spread between the 30-year mortgage loan rate and the 30-year government bond rate of the original monetary policy shocks alone and then the original policy shocks plus the contribution of the systematic response of monetary policy to financial shocks and finally the contribution of the original shocks plus the contribution of the systematic response of monetary policy to financial shocks and macro shocks. For the 2002-2007 period Eickmeier and Hofmann find relatively small contributions of the original monetary policy shocks by themselves to the actual paths of house prices, household debt, and the mortgage spread but find that adding the contributions of systematic monetary policy to financial shocks and to financial shocks plus macro shocks to the contributions of the original policy shocks increases the contribution of monetary policy to the actual paths of house prices, household debt, and the mortgage spread substantially. They conclude that monetary policy was a "key" determinant of the housing and credit boom.

Although they did not identify monetary policy shocks and did not conduct a counterfactual experiment similar to those just described, Dokko et al. (2013) compare the actual path of the federal funds rate and house prices over the period 2003-2008 with conditional forecasts from a VAR estimated using quarterly data over 1977:1-2002:4. Their model comprised the federal funds rate, real house prices, nominal residential investment expenditures as a share of nominal GDP, the inflation rate as measured by the rate of change in the core CPI, the unemployment rate, the real GDP gap, and the log level of real personal consumption expenditures. The out-of-sample forecasts were conditioned on the realizations of all macro variables except house prices, the residential investment share of GDP, and the federal funds rate. They found that the actual federal funds rate over the 2003-2008 period was within a two-standard deviation band of the conditional forecast except for 2008. However, they also found that the actual house price was significantly greater than the conditional forecast from 2003 to early 2007 and was then significantly less than the conditional forecast from late 2007-2008. A similar result was found for the residential investment share. Given that the federal funds rate was almost always within the confidence intervals of the conditional forecasts but the housing marker variables weren't, they conclude that monetary policy had only a small effect on the housing market over the period 2003-2008.

Some of the studies just summarized suggest that relatively loose monetary policy in the early to mid-2000s contributed to the housing market boom while others suggested, at most, small effects. Models and samples differed across these studies as did the counterfactual federal funds rate considered. Like Luciani (forthcoming), we consider what would have happened if the federal funds rate had followed the path suggested by a Taylor Rule. However, unlike Luciani (forthcoming) who uses counterfactual values based on a Taylor Rule computed using revised data, we consider alternative counterfactual paths based on Taylor Rules that use real-time as well revised data. This allows us to draw some tentative inferences about what would have happened if alternative variants of the Taylor Rule, which had fairly accurately described Fed policy before 2002, had been followed in real-time from mid-2001 until the end of 2007.

3. Empirical Model

We estimate a ten-variable VAR that includes typical macro activity variables (commodity prices, the price level, and the unemployment rate), the monetary policy variable (the federal funds rate), financial market variables (real stock prices and a corporate bond rate spread), and four variables that summarize conditions in the housing market—an aggregate housing price index, aggregate housing starts, the mortgage rate, and the volume of home mortgages. Specifically, the model comprises the log levels of a commodity price index, an aggregate price index, real stock prices[8], housing starts, real house prices[9], real mortgage loans made by financial institutions, and the levels of the unemployment rate, the federal funds rate, the mortgage rate, and the Baa-Aaa interest rate spread. Given the widespread perception that the Federal Reserve could be characterized as an implicit inflation targeter over much of our sample period, our price measure is the index employed in the indicated Taylor Rule specification. To help mitigate the well-known "price puzzle" often found in VAR models, we include an index of commodity prices. Since we use monthly data, we chose the unemployment rate as our aggregate real variable.[10] We employ the log levels of real house prices and housing starts and mortgage loans as price and quantity measures in the housing market. Based on the widespread perception that lending standards for residential mortgages had been relaxed during the housing price boom, ideally we would include a variable that directly measures changes in lending standards. The Senior Loan Officer Opinion Survey on Bank

[8] To generate real stock prices, we divided nominal stock prices by the aggregate price index.
[9] To generate real house prices, we divided nominal house prices by the aggregate price index.
[10] A commonly used alternative to the unemployment rate, especially in studies using quarterly or annual data, is a measure of the output gap. Consequently, we estimated a model that replaced the unemployment rate with the CBO output gap. Since GDP data are available only quarterly, the output gap measure was interpolated to monthly frequency using the RATS DISTRIB procedure with a random walk prior. We also considered the Chicago Fed National Activity Index (3-month moving average) as an alternative to the unemployment rate. Given the way this index is constructed, it can be viewed as a proxy for the output gap. Further, we also replaced the unemployment rate with industrial production. The impulse response functions for the models with alternative national activity measures were similar to those in Figure 2 and are available on request. The primary differences were short-lived significant effects of monetary policy on the Chicago Fed National Activity Index and the CBO output gap, and negative effects on stock prices in these two models that, although the point estimates were of similar magnitude to the unemployment rate model, were not significant.

Lending Practices produced by the Board of Governors contains information on changes in lending standards for residential mortgages, but this information is only available beginning in 1990, which precludes its use in our study. Consequently, we sought a proxy variable whose behavior would be importantly influenced by lending standards. The best, but admittedly imperfect, measure we found was the volume of mortgage loans. Although mortgage loans are influenced by other variables as well, changes in lending standards should be an important determinant of the volume of loans. The level of the federal funds rate is the natural choice for the monetary policy variable, and we include the mortgage rate to capture borrowing costs for the purchase of houses. Additional dimensions of financial markets are captured by including another important asset price, real stock prices, and by including a proxy for changes in the riskiness of financial instruments, the Baa-Aaa spread.[11]

The model was estimated using monthly data over the 1979:10 – 2007:12 time period.[12] The starting point is the beginning of the period in which the Fed focused first on reducing the inflation rate

[11] All the data except for commodity prices and home mortgages are revised data from FRED. When estimating the effects of monetary policy on the economy it seems best to use revised, and presumably more accurate, data rather than real-time data. Further, real-time data are not available for all the variables in the model, and Croushore and Evans (2006) found that data revisions had only a quantitatively-modest effect on estimated policy shocks and impulse response functions for shocks identified using recursive methods. Data revisions were more important for shocks identified using fully simultaneous identification schemes. Our identification method differs only slightly from a pure recursive identification.

Commodity prices are measured by the Commodity Research Bureau spot market index for all commodities, downloaded from the Global Insight database. Home mortgages are the sum of home mortgages made by U.S. chartered banks and affiliates, savings institutions, and credit unions. These data were downloaded from the Financial Accounts of the United States section of the Flow of Funds accounts on the website of the Board of Governors of the Federal Reserve. The other series with the FRED mnemonic are (1) personal consumption expenditure price index, chain type price index, PCEPI, (2) civilian unemployment rate for people 16 years of age and older, UNRATE, (3) total new privately owned housing units started, U.S. Department of Commerce, HOUST, (4) all transactions house price index, Federal Housing Finance Agency, USSTHPI, (5) effective federal funds rate, FEDFUNDS, (6) Moody's Seasoned Aaa Corporate Bond Yield, AAA, (7) Moody's Seasoned Baa Corporate Bond Yield, BAA, (8) 30-year conventional mortgage rate, Freddie Mac, MORTG, and (9) the S&P 500 Index, SP500. USSTHPI is a quarterly series, but was interpolated to monthly frequency using the RATS DISTRIB command with a random walk prior.

[12] Since the estimation period includes the 2001:07-2007:12 time period in which the federal funds rate deviated from the Taylor Rule prescription that had fairly accurately described the federal funds rate over the earlier part of the sample, we examined the stability of the model. Following Dufour (1980, 1982), we re-estimated the model over the full 1979:10-2007:12 estimation period, adding a 0-1 dummy variable for each month in which instability is suspected. Thus, we added a separate dummy variable for each month of the 2001:07-2007:12 period. Following Sims and Zha (2006), we used the Schwarz Information Criterion (SIC) to compare the models with and without the dummies. The SIC criterion indicated the unrestricted model without dummies was preferred, hence indicating stability.

and then on maintaining it at a lower level, i.e. the beginning of the period over which the Fed was a consistent (though implicit) inflation targeter. 2007:12 was chosen as the end of the sample in light of the onset of the Great Recession in that month and the subsequent reduction of the fed funds rate to the zero lower bound and adoption of non-traditional monetary policies. Three lags of all variables were employed and were sufficient to whiten the residuals of the equations of the VAR. Since the focus of the paper is on the effects of monetary policy on the housing market and since Regulation Q ceilings on deposit rates paid by financial institutions were in effect and often binding over part of our sample, we included the current and three lagged values of a Regulation Q variable developed by Duca (1996; 2009) as a deterministic variable in each equation of the VAR. This variable is designed to proxy for the disintermediation that occurred when market interest rates rose above deposit rate ceilings. Specifically, over our sample period, the variable equals the gap between the 3-year Treasury bond rate and the ceiling rate on small saver certificates when the bond rate is above the ceiling rate and is equal to 0 when the 3-year Treasury bond rate is equal to or below the ceiling rate on small saver certificates. Deposit ceiling rates were completely phased out in May 1982, and the Regulation Q dummy is zero from that date on. Further, based on Bloom's (2009) identification of uncertainty shocks and documentation of significant macro effects of these shocks, the current and three lagged values of an uncertainty measure were included as deterministic variables in each equation of the VAR. Bloom defined an uncertainty shock as occurring in periods for which values of stock market volatility were at least 1.65 standard deviations above the mean of a Hodrick-Prescott detrended measure of stock market volatility. Bloom identified 17 such shocks and the event triggering the volatility over a period extending from the early 1960s to 2010. The uncertainty measure we employ is 1 in each of the periods for which the volatility shock is associated with war, terrorism, or oil market disruption events and 0 in all other periods.[13] In light of considerable

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[13]The volatility measure is based on the Chicago Board of Options Exchange VXO index of implied stock market volatility. Since this measure is available only from 1986 on, Bloom uses actual stock market volatility for periods before 1986. Figure 1 of Bloom (2009) plots the volatility series and the 17 volatility events identified by him, and Table A1 of Bloom (2009) lists each volatility event along with the associated event that triggered the volatility. We focus on volatility events triggered by terrorism, war, and oil market disruptions. Our volatility measure is 1 in Oct.

evidence of the macro effects of oil prices, we also included the current period and three lagged values of Hamilton's net oil price measure as a deterministic variable in each equation of the VAR. Following Hamilton (2003), the net oil price variable in a given period is defined as the maximum of 0 or the difference between the log of the price of oil in that period and the maximum of the log of oil prices over the previous 3 years. Likelihood ratio tests indicated that the three deterministic variables were jointly and separately statistically significant in the VAR.

Since we are interested in the macroeconomic and housing market effects of the Federal Reserve following a Taylor Rule from 2001 on, we identify only monetary policy shocks. These shocks are identified using an over-identified structural VAR scheme whose structure is identical to a Choleski decomposition with the ordering listed earlier except for the monetary policy equation. In the identification scheme, a contemporaneous response by the Fed to movements in the macro variables (commodity prices, the inflation rate, and the unemployment rate) is allowed, but the Fed is assumed to respond only with a lag to movements in the housing market variables, the mortgage rate, real stock prices, and the spread. The Fed is thus assumed to respond contemporaneously to the variables directly related to its dual mandate, but only with a lag to variables which it doesn't directly target. As is common in light of decision and implementation lags in spending changes, a lagged effect of monetary policy on the macro and housing market variables (other than the mortgage rate) is imposed.[14] Based on efficient markets considerations, the mortgage rate, the spread, and real stock prices are ordered after the other variables and hence are assumed to respond to all other model variables, including monetary policy, contemporaneously.

The impulse response functions (IRFs) for a one standard deviation positive shock to the federal funds rate are presented in Figure 2. In each panel, the solid line is the point estimate and the dotted lines are one standard deviation confidence intervals computed using Monte Carlo simulations employing

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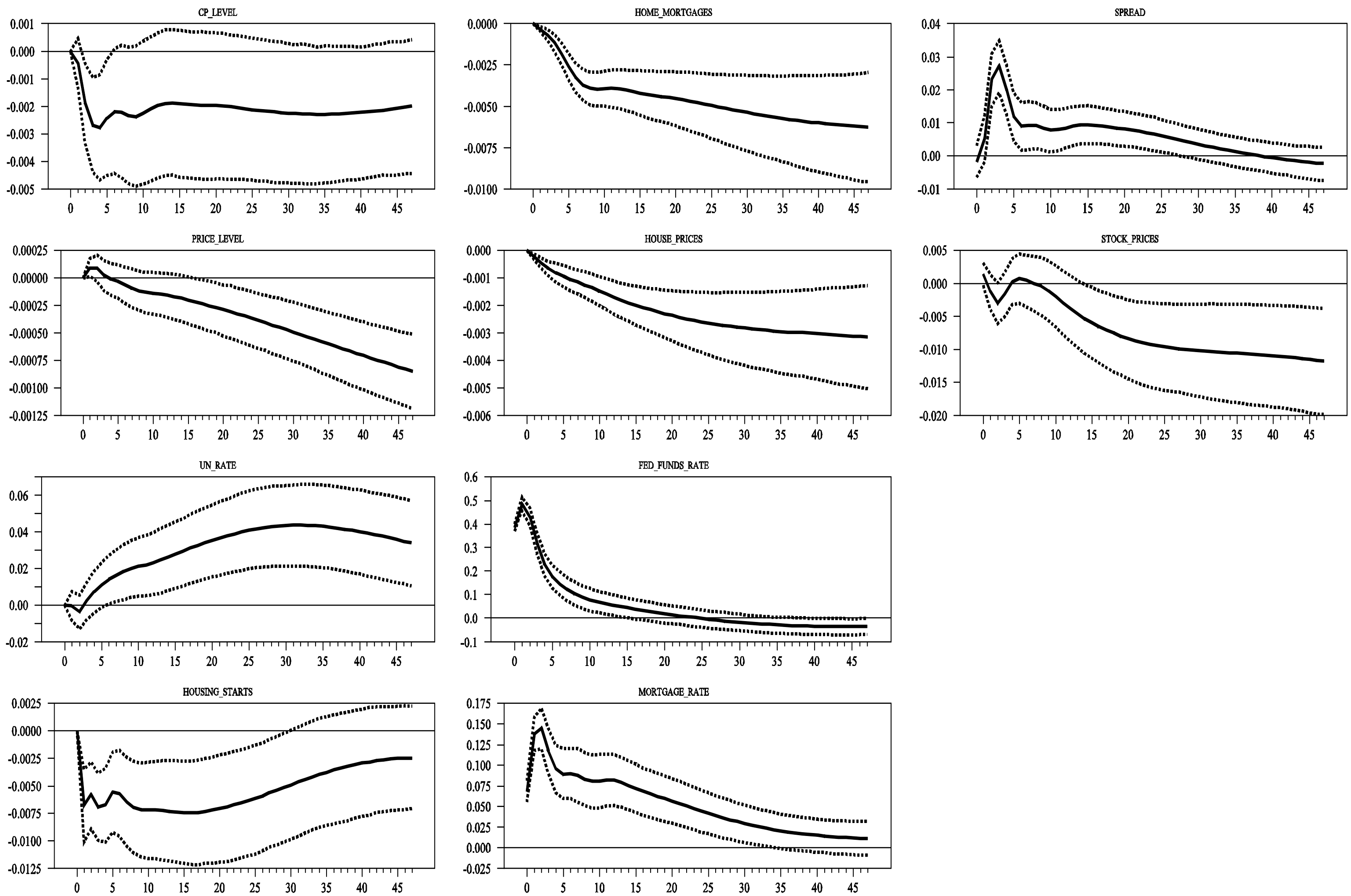
1960 (terror), Nov. 1963 (terror), Aug. 1968 (war), May 1970 (war), Dec. 1973 (oil), Nov. 1978 (oil), March 1980 (war), Nov. 1990 (war), Sept. 2001 (terror), and Feb. 2003 (war) and 0 in all other periods.

[14] A likelihood ratio test indicated the over-identifying restrictions (no contemporaneous response by the Fed to movements in the housing market variables) could not be rejected at the 5% level.

10,000 draws. The pattern of results is as expected. We see that the contractionary monetary policy shock persists but gradually weakens and dies out. Contractionary monetary policy shocks lead to negative and extended effects on commodity prices but the effect is significant only in the short-run, an extended negative effect on the price level that becomes significant after approximately 17 months, a positive effect on the unemployment rate that becomes significant after a brief lag but eventually dies out, an extended negative and significant effect on housing starts, long-lived negative and significant effects on house prices and mortgage loans, a significant, positive, extended effect on the mortgage rate, an extended positive, significant effect on the spread, and a long-lived negative and eventually significant effect on real stock prices.

Figure 2: Impulse Response Functions, Monetary Policy Shock



4. Counterfactual Experiments: Results[15]

For the period from the middle of 2001 to the end of 2007, we perform counterfactual experiments, based on the moving average representation of the VAR, that force the federal funds rate to follow the path prescribed by a Taylor Rule and then examine the implications of this path for the macroeconomy and for the housing market. The technical details of the counterfactual methodology are presented in Appendix A. To generate the point estimates of the counterfactual responses of the model variables to the counterfactual shocks to the funds rate, we assume that the disturbances to the other variables over the counterfactual period take on their expected values of zero. To get confidence intervals for the responses of the model variables, we compute 10,000 trials in which, for each trial, we randomly sample from the historical residuals for the other model variables to obtain representative values of shocks to the other model variables. These shocks are then used in conjunction with the funds rate shocks that generate the selected Taylor Rule path to compute a counterfactual path for the other model variables for that trial. We then compute standard deviations of the counterfactual paths across the trials, and these standard deviations are added to, and subtracted from, the point estimates of the counterfactual paths to obtain the confidence intervals reported in the figures below.

The counterfactual methodology is potentially subject to the Lucas critique. To address this issue, we compared the structural residuals for the federal funds rate from the estimation period with the counterfactual residuals generated over 2001:6-2007:12. The minimum and maximum values of the structural residuals are, respectively, -4.96 and 3.61. The standard error of the structural residuals is 0.91. For the counterfactual residuals based on the Taylor Rule using real-time data for the personal consumption expenditure deflator, the minimum and maximum values are -1.53 and 2.63, respectively, and the standard error of the counterfactual residuals is 0.73. The range of the counterfactual residuals for the Taylor Rule using revised data is –1.94 to 2.31; the standard error is 0.69. Thus, the counterfactual residuals fall entirely within the range of the structural residuals, and the standard errors for the counterfactual residuals, although

[15] Precedents for the type of counterfactual analysis conducted here include Christiano (1998) and Fackler and Rogers (1995). For a counterfactual analysis where the objective is a forecast of average inflation over a policy horizon of two years, see Fackler and McMillin (2011).

somewhat smaller than for the structural residuals from the estimation period, are quite comparable in magnitude. In light of these results, it seems unlikely that economic agents would have interpreted the shocks generated by the counterfactual experiments as monetary policy regime shifts.

In generating the Taylor Rule path for the real-time versions of the Taylor rule, we start with FOMC meeting-frequency data and then aggregate to monthly data. As noted earlier in our discussion of Figure 1, our real-time Taylor Rule measures are computed using the average of the current and three-quarter-ahead forecasts of both inflation (from the Greenbook) and the output gap (separately-provided Staff forecasts not in the Greenbook but available to FOMC members before each meeting).[16] Using this data, for each meeting we compute the Taylor Rule value of the funds rate using the formula in footnote 1. We aggregate to the monthly frequency as follows. For months in which there is no FOMC meeting, we use the implied Taylor Rule value form the most recent meeting. For months in which there is an FOMC meeting, we compute a weighted average of the implied Taylor Rule value from the prior FOMC meeting and the current-month meeting. For these months, the weight for the value from the previous meeting is the number of days in the current month before the meeting is held divided by the number of days in the month and the weight for the value set at the current-month meeting is the number of days in the month this value prevails divided by the number of days in the month. The monthly value of the actual funds rate target is computed in an analogous fashion.

To compute the monthly value of the Taylor Rule value based on revised data, we first compute the quarterly value of the implied Taylor Rule target (since the GDP deflator and the CBO output gap are available only quarterly) using only current period data and then interpolate this to monthly using the RATS DISTRIB procedure with a random-walk prior. The monthly values from this procedure average to the quarterly value.

In addition to the revised-data and real-time Taylor Rule values based on the GDP deflator and, alternatively, the core PCE deflator using Taylor's original equal weights on the deviation of inflation from

[16] Both the Greenbooks and the Staff forecasts of the output gap can be found at http://www.philadelphiafed.org/research-and-data/real-time-center/greenbook-data/.

target and the output gap that are presented in Figure 1, we also computed revised-data and real-time Taylor Rule values using the 0.5 weight on the deviation for inflation from target and a 1.0 weight on the output gap. Implicitly, these alternative weights place relatively more importance on labor market conditions, which may reflect preferences of some policy makers. However, our focus in the text is on the values computed using the original Taylor Rule weights for revised data for the GDP deflator and real-time data for the core PCE deflator. Graphs of counterfactuals for other Taylor Rule values are reported in the Appendix.

We first consider the counterfactual results using the original Taylor Rule computed with revised data. The results for housing market variables are presented in Figure 3, and the results for macroeconomic and financial market variables are presented in Figure 4. Figure 3 suggests that setting the funds rate at the substantially higher level prescribed by the original Taylor Rule computed with revised data would have led to significantly lower housing starts, home mortgages outstanding, and real housing prices than actually experienced. We see that the confidence intervals for the counterfactual values begin to move below the actual values of these variables in 2004, and the confidence interval remains below the actual value for the rest of the counterfactual simulation period for home mortgages and real housing prices.

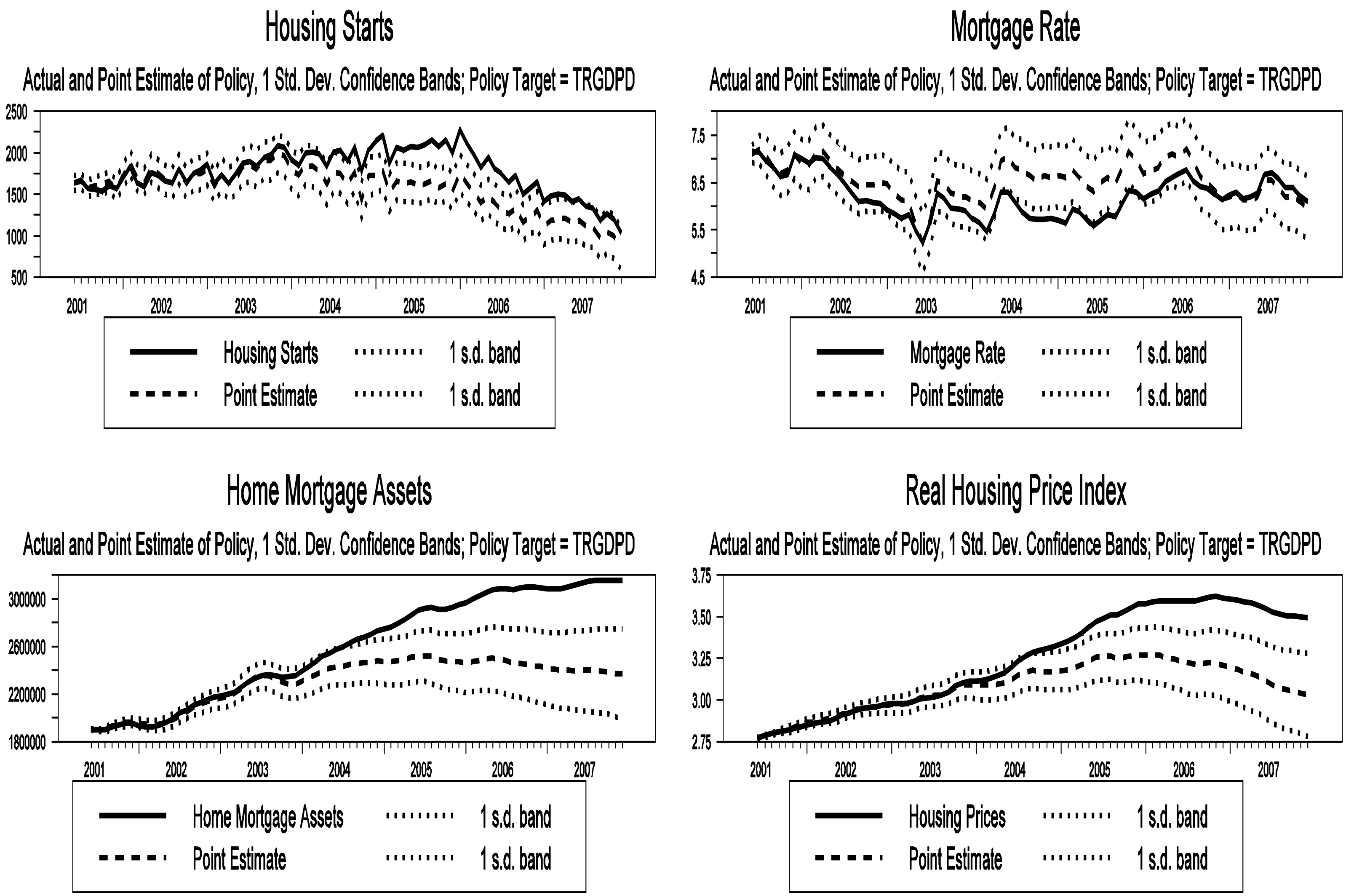
The lower, right panel of Figure 3 shows that actual real housing prices, and the point estimate of these prices, were nearly identical in 2003:9. Actual real housing prices peaked in 2006:12. Over this 40 month period, for every $1000 invested in housing in 2003:9, by 2006:12 the holder of real estate would own property worth $1187, an annualized growth rate of about 5.3%. Alternatively, under the counterfactual Taylor Rule used in Figure 3, home values per $1000 at the beginning of the period would be worth about $1055, an annualized growth rate of about 1.6%. The upper edge of the confidence band would have implied a 2006:12 value of $1100, an annualized growth of about 2.9%. From a slightly different perspective, our point estimate of housing prices under the assumed Taylor Rule would have been about 13% lower at the end of 2006; even the upper edge of the confidence band would have been about 11% lower than actual. By comparison, Bean et al. (2010) report that in their analysis U.S. housing prices would have been about 7.5% lower with their alternative policy, reasonably close to our estimates.

We also note that our point estimate of housing starts falls below the actual level in April, 2003, and remains below actual until the end of the sample period, 2007:12. Over this time, actual housing starts averaged 1,810 thousand units per month while our point estimate of starts averaged 1,524 thousand units, on average 286 thousand fewer units per month. Between April 2003 and the end of the sample, the cumulative shortfall of the point estimate compared to actual was 16,323 thousand units. The upper bound of the one standard deviation band fell below actual between 2004:8 and 2007:6. The average difference was 159 units per month and the cumulative difference was 5,589 units.

Finally, the point estimate of the home mortgages assets held by financial institutions fell below actual in 2003:8 and remain below for the remainder of the period, ending about 25% lower than the actual volume of these assets on financial institution balance sheets. The upper bound of the one standard deviation band fell below actual in 2004:7 and also remained below until the end of the period and ended about 13% lower than average.

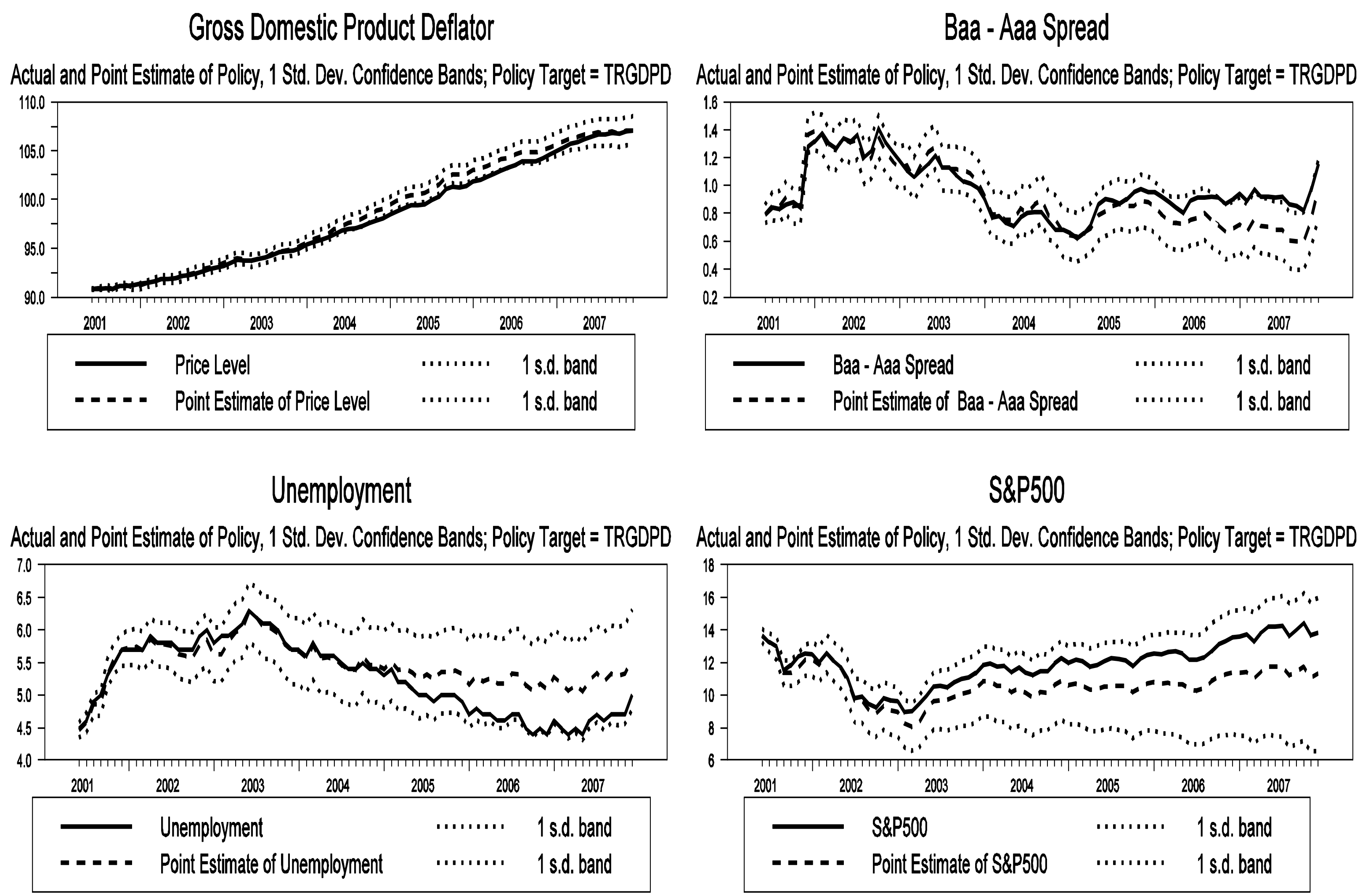
These results suggest that with the revised-data GDP deflator as the price index used in the Taylor Rule as specified above, policy would have notably reduced housing market activity.

Figure 3: Housing Market Variables



Although following the original Taylor Rule computed using revised data, as illustrated in Figure 3, would have dampened the housing market, we see from Figure 4 that there would have been little significant effects on the overall economy, a result similar to Luciani (forthcoming). Although the point estimate of the counterfactual unemployment rate is above the actual value from 2004 on and the point estimate of counterfactual real stock prices is below the actual value from 2003 on, the actual values always fall within the confidence intervals for the counterfactual. There is essentially no difference between the counterfactual and actual GDP deflator, and the spread is not significantly higher as a result of the more contractionary monetary policy. Overall, the results suggest the more contractionary policy called for by the original Taylor Rule with revised data could have dampened the housing market without any serious macroeconomic consequences.

Figure 4: Macroeconomic and Financial Market Variables



The housing market results based on the real-time Taylor Rule values for core PCE presented in Figure 5 are quite different from the results in Figure 3 based on a revised-data Taylor Rule that uses the GDP deflator. We see that, although the counterfactual point estimates of housing starts, home mortgages, and real housing prices lie below the actual values for part of the counterfactual period, the confidence intervals for these three variables always include the actual value. Consistent with Figure 1, the counterfactual and actual values of the mortgage rate begin to diverge in mid-2005, and by the end of the counterfactual simulation period, the confidence interval is slightly below the actual value. Thus, when real-time data for the core PCE and the output gap are used to construct the counterfactual Taylor Rule funds rate path, housing starts, home mortgages, and real house prices do not differ significantly from the actual values unlike what we observed when revised data for the GDP deflator were used to compute the counterfactual funds rate path. This is not surprising, however, in light of the bottom plot in Figure 1 which shows that the counterfactual path of the funds rate based on a real-time Taylor Rule using core PCE is much closer to the actual target rate than is the counterfactual path based on revised GDP deflator data. From Figure 6, we see that, as was the case in Figure 4, the actual values of the macroeconomic and financial market variables lie on or within the confidence intervals for counterfactual path.

We also considered additional Taylor Rule paths for the funds rate; we summarize the results at this point and present figures for the housing market results in the appendix. One alternative path was based on the original weight Taylor Rule using revised data for core PCE. As noted in Section 1, when revised values of core PCE replace revised GDP deflator values in the Taylor rule, the implied path of the funds rate still deviated substantially from the actual path, but the mean absolute error for revised core PCE compared to the revised GDP deflator was much smaller: 1.21 versus 1.85; see appendix Figure A1. Not surprisingly, we found that the implied reduction in housing starts, home mortgages, and real housing prices was much smaller in magnitude than in Figure 3. A second alternative path was generated from the original-weight Taylor Rule using real-time data for the GDP deflator as well as real-time output gap data. Again, as noted in Section 1, when real-time values of the GDP deflator and output gap replaced revised GDP deflator and output gap values in the Taylor rule, the implied path of the funds rate was substantially closer to the actual path; the mean absolute error for the real-time GDP deflator compared to the revised GDP deflator was much smaller: 0.60 versus 1.85. We found that there is essentially no difference between the point estimate of the counterfactual path and the actual value of housing starts, home mortgages, and real housing prices. Towards the end of the counterfactual sample, the counterfactual mortgage rate is slightly but significantly below the actual value. As before, there were no significant macro effects; see appendix Figure A2.

We also considered two Taylor Rule paths for real-time Taylor rules that specified a weight of 0.5 on the deviation of inflation from target and a weight of 1.0 on the output gap. Both used real-time output gap data, and the first employed real-time data for the GDP deflator and the second employed the real-time core PCE deflator; see, respectively, appendix Figures A3 and A4. For both we found that the confidence intervals for the counterfactuals virtually always included the actual values of housing starts, home mortgages, and real housing prices; any deviations were short-lived and of small magnitude. For both, the confidence interval for the counterfactual fell below the actual mortgage rate towards the end of the counterfactual simulation period. As before, there were no significant macro effects.

Figure 5: Housing Market Variables

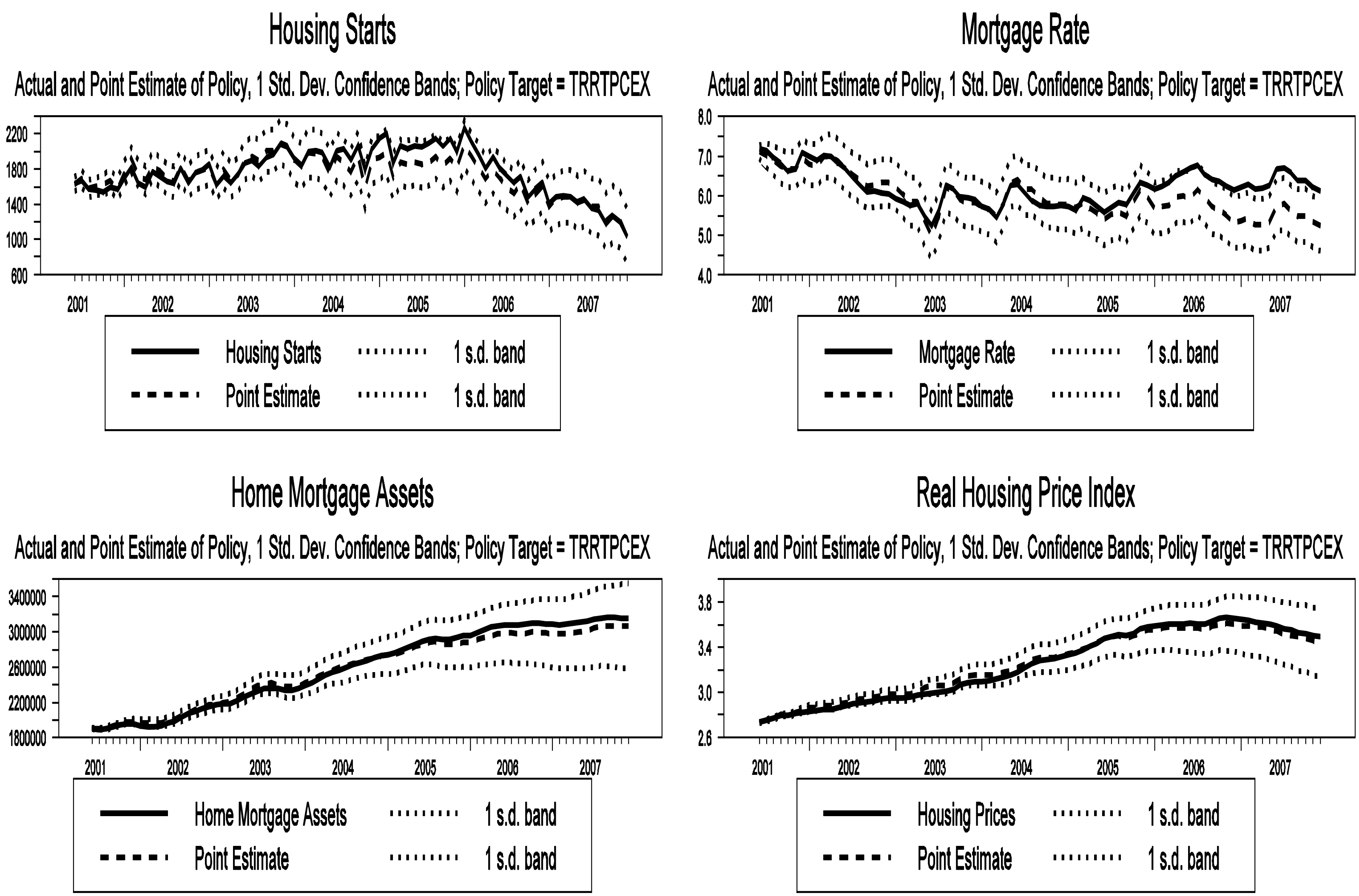
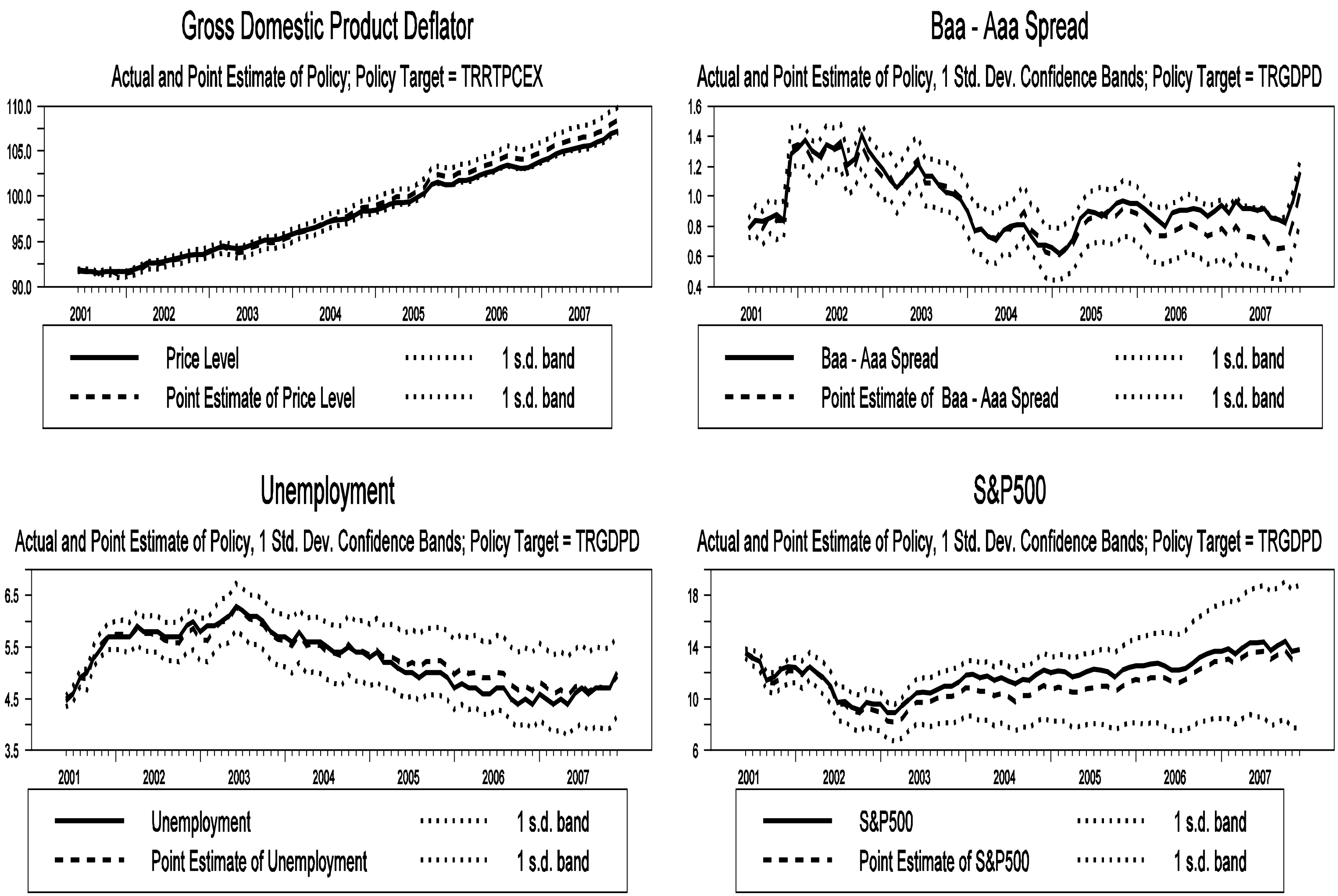


Figure 6: Macroeconomic and Financial Market Variables



5. Discussion

Our analysis is intended to shed light on the issue of whether monetary policy in the several years prior to the housing boom and bust contributed to this particular housing cycle. As such, we have estimated and analyzed a model that allows a comparison between actual policy and the path of the federal funds rate suggested by several alternative Taylor Rule specifications. Given the widespread use of the Taylor Rule in macro models and given that the Taylor Rule approximately describes policy for a decade or so prior to the housing cycle, it is a natural approach to employ.

In contrast to other recent studies using counterfactual techniques, we compare the implications of alternative Taylor Rule paths for the federal funds rate for Taylor Rules based on real-time data as well as Taylor Rule paths based on revised data. Of the earlier studies, only Luciani (forthcoming) analyzed the implications of following a Taylor Rule path, and he considered only revised data in the construction of the Taylor Rule path. We find important differences in the implications for the housing market of using a counterfactual path based on revised data and a counterfactual path based on real-time data. We also consider alternative inflation measures (one based on the GDP deflator and another based on the core PCE deflator) and alternative weights in the Taylor Rule (weights of 0.5 on both the inflation and output gaps, the original Taylor Rule weights, and weights of 0.5 on the inflation gap and 1.0 on the output gap, the weights preferred by Yellen (2012)).

Our results can be summarized in the following way:

First, when revised data for the GDP deflator and the output gap and the original Taylor Rule weights were used, following the counterfactual Taylor Rule path would have generated significantly lower housing starts, home mortgages outstanding, and real house prices than actually observed. The mortgage rate would have differed from the actual value in only a transitory and quantitatively small way. However, the reductions in housing starts, home mortgages outstanding, and real house prices, although still significant, would have been much smaller if revised data for the core PCE deflator along with the original Taylor Rule weights had been used to generate the counterfactual federal funds rate path. In both cases, the counterfactual values for the macro variables would not have differed in a significant way from their actual values.

Second, when real-time data for the core PCE deflator and the output gap and the original Taylor Rule weights were used, the counterfactual path for the federal funds rate was much closer to the actual path than when the revised GDP deflator was used, and there would have been essentially no significant differences between the actual values of housing starts, home mortgages outstanding, and real house prices and the counterfactual values. As before, the mortgage rate would have differed from the actual value in only a transitory and quantitatively small way, and the counterfactual values for the macro variables would not have differed in a significant way from their actual values. The same results held if real-time data for the GDP deflator had been used in place of real-time core PCE data in the Taylor Rule.

Third, when real-time data for either the GDP deflator or the core PCE deflator was used along with real-time output gap data and the Yellen-preferred weights on the inflation and output gaps, the results for both the housing market variables and the macro variables were essentially the same as those described in part b.

The debate between Bernanke and Taylor hinges on the correct identification of the Taylor rule. Whether strictly following a Taylor Rule in the run-up to the Great Recession would have dampened the housing market and thereby perhaps affected the timing and depth of the Great Recession depends importantly on how the Taylor path is constructed. When the Taylor Rule path was computed using revised data we found a notable impact on key housing market variables, supporting Taylor's critique of Fed policy. However the bulk of our evidence suggests that policy as it would have been conducted under our real-time Taylor Rules would not have had any significant impact on the housing market variables. This conclusion is generally robust with regard to the price index used as well as the relative weights used on the inflation and output gaps. As mentioned above, Bernanke (2010) has argued that policy is made in real-time with forecasts of key economic variables, consistent with our construction of the real-time Taylor Rule variants investigated here. Thus, the weight of our evidence is consistent with the view that policy was not an important factor in the housing market cycle and the Great Recession that followed.

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Appendix

I: Counterfactual Experiments—Methodology

Our counterfactual experiments force the federal funds rate to follow the path prescribed by the selected Taylor Rule over the period from the middle of 2001 to the end of 2007. We then examine the implications of this path for the macroeconomy. In this appendix, we outline the framework for the counterfactual analysis.

We start with a structural model:

(A1) $$y_t = A_0 y_t + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \mu_t$$

where the A_i are the structural coefficients and the μ_t are the structural shocks. Let $e_t = (I-A_0)^{-1}\mu_t$ represent the reduced form shocks and Π_i the reduced-form coefficient matrices. Define $\Pi(L) = (I- \Pi_1 L-\ldots \Pi_{-p} L^p)$. The moving average matrix is given by $C(L) = [\Pi(L)]^{-1}$, with $C_0 = I$:

(A2) $$y_t = \Pi(L)^{-1} e_t = C(L) e_t = \sum_{s=0}^{\infty} C_s e_{t-s}$$

The C_i are determined by the following recurrence relations:

$$C_1 = \Pi_1 C_0$$

$$C_2 = \Pi_1 C_1 + \Pi_2 C_0$$

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$$C_j = \Pi_1 C_{j-1} + \ldots + \Pi_p C_{j-p}.$$

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Equation (A2) is written in terms of the reduced-form shocks. It can be re-written in terms of the structural shocks as

(A3) $$y_t = \sum_{s=0}^{\infty} [C_s (I - A_0)^{-1}](I - A_0)\, e_{t-s} = \sum_{s=0}^{\infty} D_s \mu_{t-s}$$

where the μ_t represent the structural shocks in equation (1) and $D_s = C_s(I - A_0)^{-1}$. For a particular period t+j, equation (A3) may be written as:

(A4) $$y_{t+j} = \sum_{s=0}^{j-1} D_s \mu_{t+j-s} + \sum_{s=j}^{\infty} D_s \mu_{t+j-s}$$

which represents the historical decomposition. The second term on the right hand side represents the expectation of y_{t+j} given information available at time t, the "base projection" of the vector y. The first term on the right hand side shows the difference between the actual series and the base projection due to the structural innovations in the variables subsequent to period t; that is, it shows that the gap between an actual series and its base projection is the sum of the (weighted) contributions of the structural innovations to the individual series in the analysis. Thus, the actual data at period t+j is the sum of the base projection and the weighted structural innovations to the system variables. If the model is just-identified, then under the usual assumption that the covariance matrix of the structural residuals is diagonal, these structural innovations are orthogonal to one another.[17]

We next use equation (A4) to construct counterfactual (CF) paths for the variables in the system. A historical decomposition uses the observation that for the actual data, the sum of the base projection and the weighted shocks subsequent to the projection add to the data itself. To construct a CF path, we modify this in the following way. Given a base projection as computed for the period estimated through 2001:6, suppose the shocks beginning in 2001:7 are selected to follow some other path. For our point experiments, we will use shocks for the federal funds rate that force it along the interest rate trajectory given by the selected Taylor Rule. Given this alternative interest rate trajectory, we investigate two types of counterfactuals. First, we compute the point estimate of this counterfactual, which assumes that the disturbances to the other equations take their expected values of zero. The results of this exercise provide clear assessments of the path of the economy under the selected Taylor Rule compared with the actual path of the economy under policy as actually pursued. Second, to find the variability of the variables in our model around this point estimate, we conduct a number of trials. For each trial, we compute the shocks needed to attain the selected Taylor Rule path for the funds rate when taking random draws from the historical shocks for the other system equations. Combining the results of these trials allows us to compute the variability of each variable

[17] Although we use a near-Choleski decomposition to identify the monetary policy shock, we note that the approach we outline can also be implemented with alternative identifying schemes, including the long-run restriction approach of Blanchard and Quah (1989), the short-run identification technique of Bernanke (1986), the signs restriction approach of Uhlig (2005), or a blend of the alternative identification methods.

around the point estimate, conditional on the economy experiencing shocks over the period of the trials consistent with the historical data. With a just-identified structural model, the shocks will, by construction, be orthogonal in which case our computation of the counterfactual policy shock would have no first-order implications for shocks to the other variables. With our over-identified system, however, this statement holds only as an approximation. Finally, note that the counterfactual paths constructed here are intuitively simple for a policy maker to construct; given the estimated VAR, all that must be done to produce the counterfactual path for the system is to specify the desired path for the variable of interest.

We construct the counterfactual shocks to force the fed funds rate along the Taylor Rule path in the following way. Equation (A3) shows the historical decompositions in terms of model parameters and structural shocks. Equation (A4) shows the decomposition for a particular period t+j in terms of the base projection conditional on the historical shocks to that point and the contributions of shocks subsequent to time t. Consider equation (A4) for j=1:

(A5) $$y_{t+1} = D_0\mu_{t+1} + \sum_{s=j}^{\infty} D_s\mu_{t+1-s} = D_0\mu_{t+1} + BP_t$$

Note that the ith equation of this system is:

(A6) $$y_{i,t+1} = d_{0,ii}\mu_{i,t+1} + \sum_{j\neq i} d_{0,ij}\mu_{j,t+1} + BP_{1,i,t}$$

where $BP_{k,i,t}$ is the k-period ahead base projection for the ith equation at time t and where $d_{k,ij}$ is the (i,j) element of the matrix D_k. Suppose we want to find the shock to this equation that will produce a predetermined value for $y_{i,t+1,}$ denoted by $y^*_{i,t+1}$, given values for the other shocks. To so do, solve the following equation for $\hat{\mu}_{i,t+1}$:

(A7) $$y^*_{i,t+1} = d_{0,i}\hat{\mu}_{i,t+1i} + \sum_{j\neq i} d_{0,ij}\mu_{j,t+1} + BP_{1,i,t}$$

The solution for which is

(A8) $$\hat{\mu}_{i,t+1} = (d_{0,ii})^{-1}\left[y^*_{i,t+1} - BP_{1,i,t} - \sum_{j\neq i} d_{0,ij}\mu_{j,t+1}\right].$$

Proceeding in a similar manner, the structural residual needed to achieve a particular value for $y_{i,t+2}$, denoted by $y^*_{i,t+2}$ is

(A9) $$\hat{\mu}_{i,t+2} = (d_{0,ii})^{-1}\left[y^*_{i,t+2} - BP_{2,i,t} - \sum_{j\neq i} d_{0,ij}\mu_{j,t+2} - \sum_{j\neq i} d_{1,ij}\mu_{j,t+1} - d_{1,ii}\hat{\mu}_{i,t+1}\right]$$

Similar iterations produce a path of structural shocks that generate a path for $y_{i,t+j}$ that matches a target path $y^*_{i,t+j}$ for j=1,…,T where T is the desired horizon. As indicated above, the values of the shocks to equations other than that for the interest rate are set to zero for computation of the point estimates and take on values resulting from random draws from the estimated residuals for computation of the confidence bands.

II. Counterfactual Experiments—Alternative Taylor Rule Paths

Figure A1: Original weight Taylor Rule using revised data for core PCE

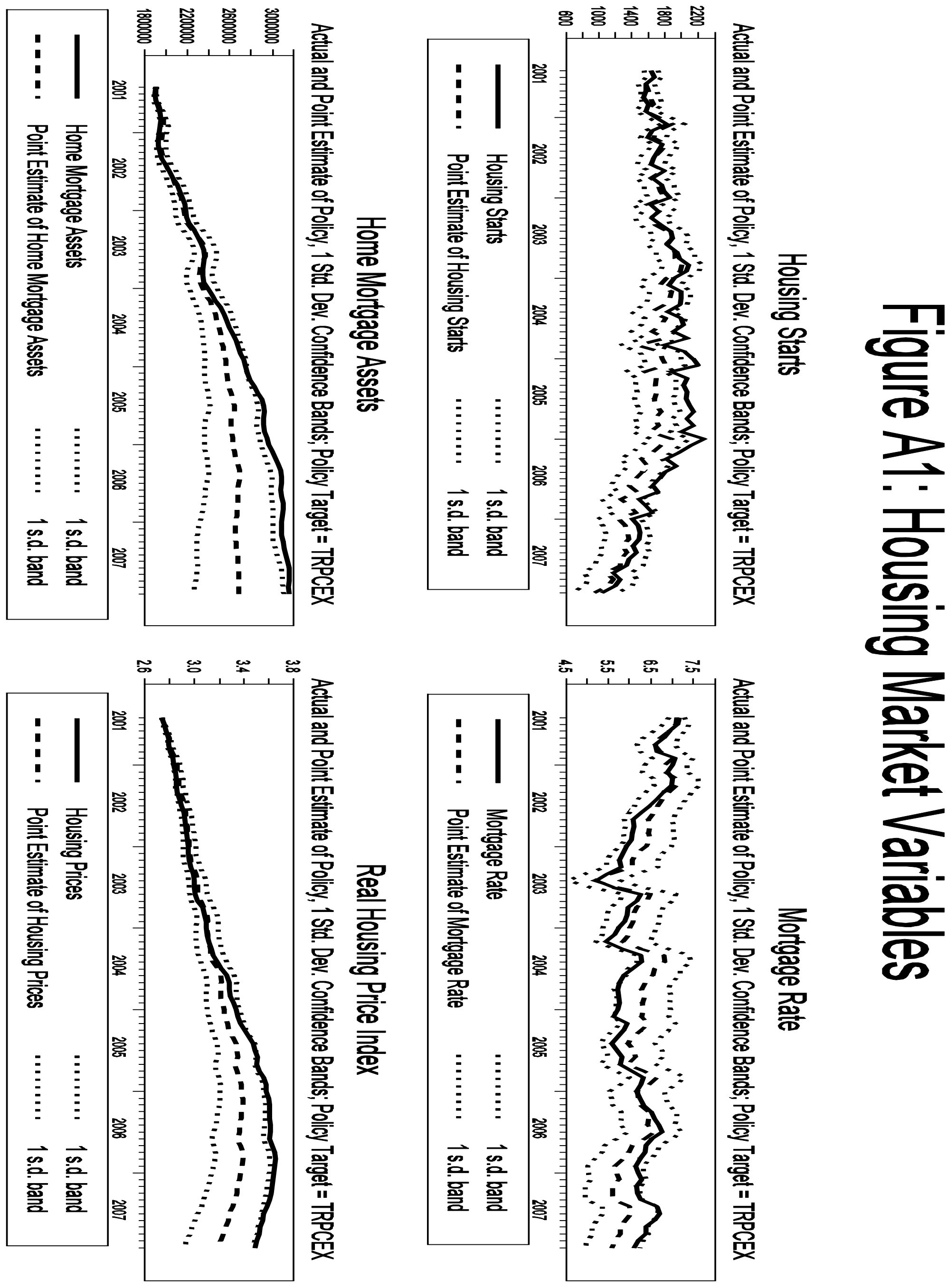

Figure A2: Original weight Taylor Rule using real-time data for the GDP deflator

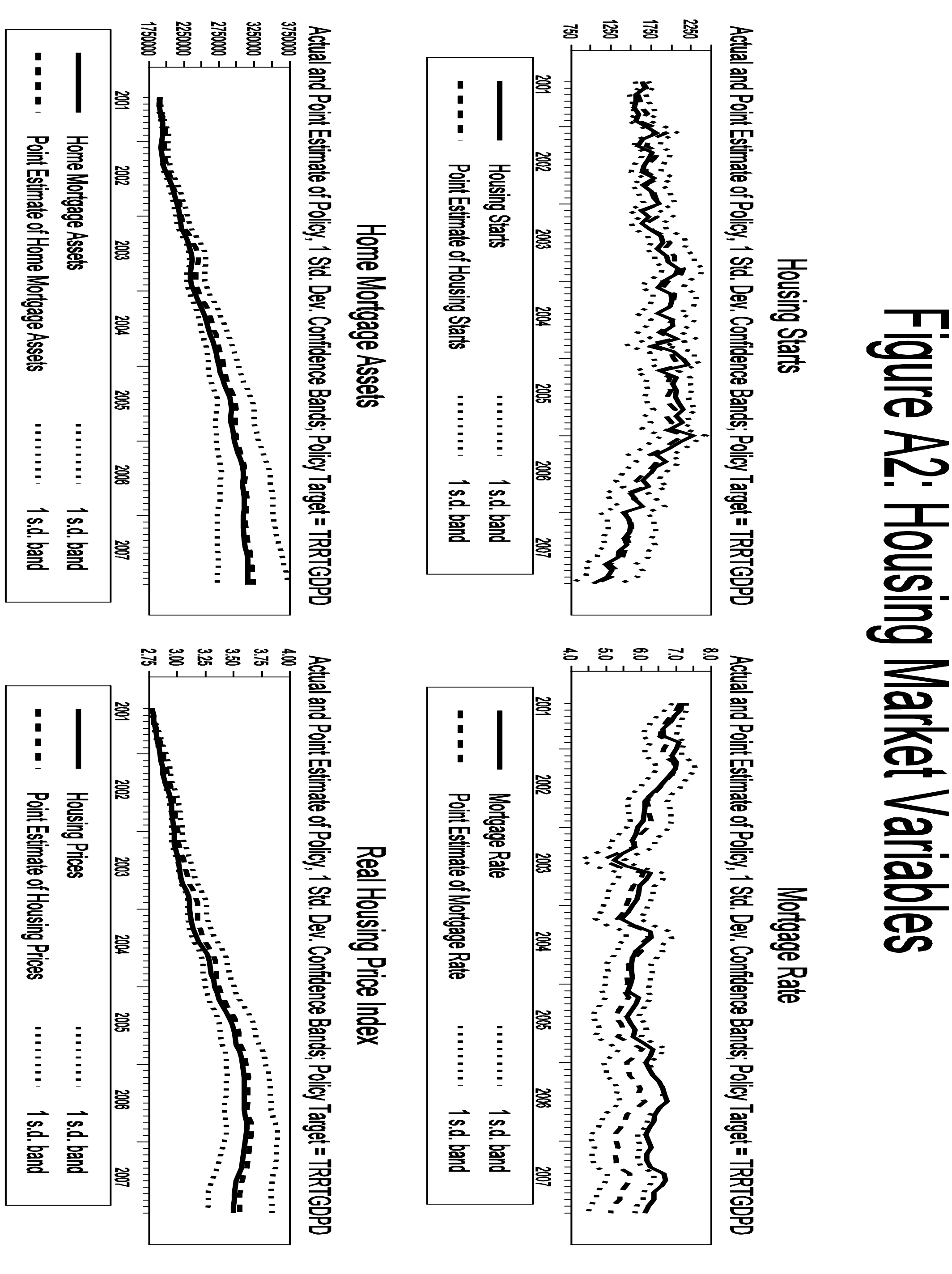

Figure A3: Alternative weight Taylor Rule using real-time data for the GDP deflator

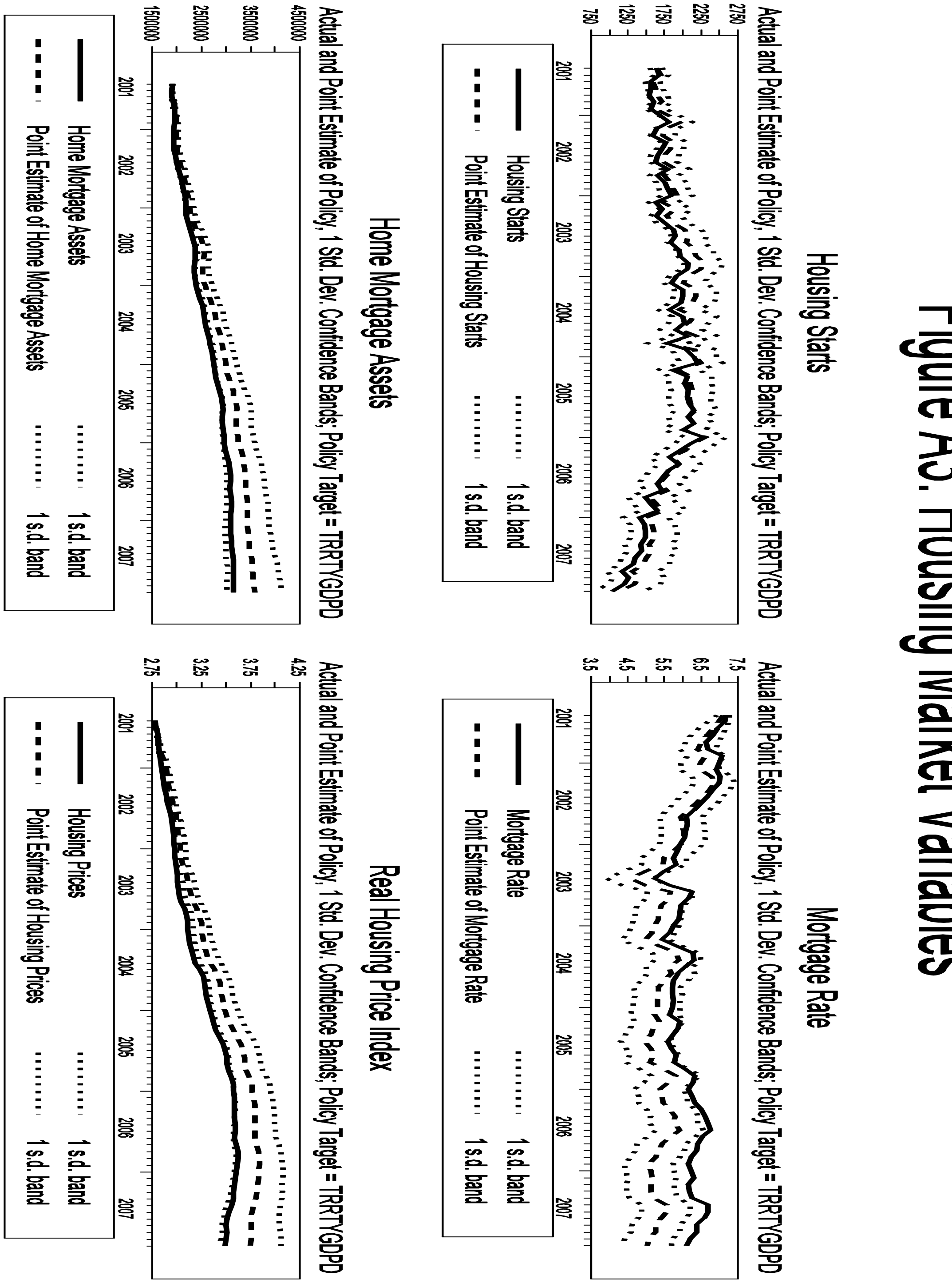

Figure A4: Alternative weight Taylor Rule using real-time data for the core PCE