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International Journal of Central Banking

Monetary Policy Lessons from the Global Crisis

Introduction to a Special Issue of the International Journal of Central Banking

Giancarlo Corsetti, Andrew Levin, Frank Smets, and Carl Walsh

The global crisis of 2007–09 led central banks to employ an array of traditional and non-traditional monetary policy tools. Many central banks cut policy rates to levels close to zero, and a few of them provided explicit forward guidance about the anticipated future path of policy rates. Some followed a quantitative easing strategy, while others took actions aimed specifically at improving conditions in private credit markets. Finally, with signs of economic recovery becoming evident, central banks refined their exit strategies for unwinding these extraordinary policy measures.

These issues are analyzed in this volume of the *International Journal of Central Banking* (IJCB), which includes the papers, discussions, and commentaries that were presented at the second annual IJCB Monetary Policy Conference that was hosted by the Bank of Japan on September 16–17, 2010. In addition to these contributions, the conference included a keynote speech by Governor Masaaki Shirakawa (Bank of Japan) and a policy panel in which Stephen Cecchetti (Bank for International Settlements), Ryuzo Miyao (Bank of Japan), John Murray (Bank of Canada), Francesco Papadia (European Central Bank), Lars Svensson (Sveriges Riksbank), and John Taylor (Stanford University) discussed the implications of the global crisis for macroeconomic and monetary policy research.

The first two papers in this issue consider the characteristics and effects of *unconventional monetary policies*. One of these papers—"The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases" by Joseph Gagnon, Matthew Raskin, Julie Remache, and Brian Sack—presents evidence that the Federal Reserve's large-scale securities purchases that were initiated in late 2008 led to substantial reductions in longer-term interest rates; moreover, those reductions primarily reflected lower risk premiums rather than reduced expectations of future short-term interest rates. This paper is discussed by Tsutomu Watanabe (Hitotsubashi University). The second paper—"On the Quantitative Effects of Unconventional Monetary Policies in Small Open Economies" by Javier

García-Cicco—analyzes such policies in a small open-economy model of the Chilean economy in which the central bank has several distinct policy instruments. This paper is discussed by Kosuke Aoki (Bank of Japan). Lawrence Christiano (Northwestern University) provides broader commentary on the rationale for unconventional monetary policies.

Another pair of papers uses empirical analysis to investigate *the determinants of inflation and inflation expectations*. One of these papers—"Did Easy Money in the Dollar Bloc Fuel the Oil Price Run-Up?" by Christopher Erceg, Luca Guerrieri, and Steven Kamin—uses a dynamic general equilibrium model to analyze how various shocks affect global oil prices in a setting where the currencies of many emerging-market economies are pegged to the U.S. dollar. This paper is discussed by Giancarlo Corsetti (Cambridge University, Rome III, and CEPR). The other paper—"Did the Crisis Affect Inflation Expectations?" by Gabriele Galati, Steven Poelhekke, and Chen Zhou—analyzes daily data on break-even inflation for the euro area, the United Kingdom, and the United States and gauges the extent to which long-run inflation expectations in each economy remained well anchored during the crisis. Shigenori Shiratsuka (Bank of Japan) discusses this paper and presents comparable evidence on the evolution of Japanese long-term inflation expectations. Fumio Hayashi (Hitotsubashi University) provides broader commentary on these issues.

The final pair of papers considers the relationship between *monetary policy and housing booms*. One of these papers—"The Effects of Housing Prices and Monetary Policy in a Currency Union" by Oriol Aspachs-Bracons and Pau Rabanal—uses a New Keynesian model of a currency area with durable goods to investigate the roots of soaring house prices in the case of Spain. Robert King (Boston University) discusses this paper. The other paper—"Risky Mortgages in a DSGE Model" by Chiara Forlati and Luisa Lambertini—develops a model with housing and risky mortgages and finds that economies with less idiosyncratic volatility are characterized by higher loan-to-value ratios and lower rates of mortgage default. This paper is discussed by Tomoyuki Nakajima (Kyoto University). John C. Williams (Federal Reserve Bank of San Francisco) provides broader commentary and explores the factors that may contribute to the onset of a housing bubble.

The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases*

Joseph Gagnon,[a] Matthew Raskin,[b] Julie Remache,[b] and Brian Sack[b]
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Since December 2008, the Federal Reserve's traditional policy instrument, the target federal funds rate, has been effectively at its lower bound of zero. In order to further ease the stance of monetary policy as the economic outlook deteriorated, the Federal Reserve purchased substantial quantities of assets with medium and long maturities. In this paper, we explain how these purchases were implemented and discuss the mechanisms through which they can affect the economy. We present evidence that the purchases led to economically meaningful and long-lasting reductions in longer-term interest rates on a range of securities, including securities that were not included in the purchase programs. These reductions in interest rates primarily reflect lower risk premiums, including term premiums, rather than lower expectations of future short-term interest rates.

JEL Codes: E43, E52.

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1. Introduction

In December 2008, the Federal Open Market Committee (FOMC) lowered the target for the federal funds rate to a range of 0 to 25 basis points. With its traditional policy instrument set as low as possible, the Federal Reserve faced the challenge of how to further ease the stance of monetary policy as the economic outlook deteriorated. The Federal Reserve responded in part by purchasing substantial quantities of assets with medium and long maturities in an effort to drive down private borrowing rates, particularly at longer maturities. These large-scale asset purchases (LSAPs) have greatly increased the size of the Federal Reserve's balance sheet, and the additional assets may remain in place for years to come.

To be sure, the Federal Reserve undertook other important initiatives to combat the financial crisis. It launched a number of facilities to relieve financial strains at specific types of institutions and in specific markets. In addition, in an attempt to provide even more stimulus, it used public communications about its policy intentions to lower market expectations of the federal funds rate in the future. All of these strategies were designed to ease financial conditions and to support a sustained economic recovery. Over time, though, the credit extended by the liquidity facilities has declined and the dominant component of the Federal Reserve's balance sheet has become the assets accumulated under the LSAP programs.

The decision to purchase large volumes of assets came in two steps. In November 2008, the Federal Reserve announced purchases of housing agency debt and agency mortgage-backed securities (MBS) of up to \$600 billion. In March 2009, the FOMC decided to substantially expand its purchases of agency-related securities and to purchase longer-term Treasury securities as well, with total asset purchases of up to \$1.75 trillion, an amount twice the magnitude of total Federal Reserve assets prior to 2008.[1] The FOMC stated that

[1]The Treasury Department also established a program to purchase agency MBS beginning in September 2008. By its termination at year-end 2009, it had purchased \$220 billion of such securities. This program was much smaller than the Federal Reserve LSAPs and no specific purchase amount targets were announced, so it is not included in our analysis.

the increased purchases of agency-related securities should "provide greater support to mortgage lending and housing markets" and that purchases of longer-term Treasury securities should "help improve conditions in private credit markets."

In this paper, we review the Federal Reserve's experience with implementing the LSAPs and describe some of the challenges raised by such large purchases in a relatively short time. In addition, we discuss the economic mechanisms through which LSAPs may be expected to stimulate the economy and present some empirical evidence on those effects. In particular, LSAPs reduce the supply to the private sector of assets with long duration (and, in the case of mortgage securities, highly negative convexity) and increase the supply of assets (bank reserves) with zero duration and convexity.[2] To the extent that private investors do not view these assets as perfect substitutes, the reduction in supply of the riskier longer-term assets reduces the risk premiums required to hold them and thus reduces their yields. We assess the extent to which LSAPs had the desired effects on market interest rates using two different approaches and find that LSAPs caused economically meaningful and long-lasting reductions in longer-term interest rates on a range of securities, including securities that were not included in the purchase programs. We show that these reductions in interest rates primarily reflect lower risk premiums rather than lower expectations of future short-term interest rates.[3] We briefly examine the experiences of Japan and the United Kingdom with LSAPs and find effects that are generally consistent with those found in the United States. We conclude with a discussion of issues raised by these policies and potential lessons for implementing monetary policy at the zero bound in the future.

[2]Negative convexity arises from the ability of mortgage borrowers to prepay their loans. As interest rates fall, the incentive to prepay increases, generally resulting in an increase in prepayments to MBS holders. This effect causes the duration of MBS to fall as interest rates decline and vice versa. Convexity is explained in more detail in the next section.

[3]As we discuss below, these risk premiums, or excess expected returns, arise due to interest rate, credit, or liquidity risk, or other characteristics that make the assets' returns uncertain.

2. How Large-Scale Asset Purchases (LSAPs) Affect the Economy

The primary channel through which LSAPs appear to work is by affecting the risk premium on the asset being purchased. By purchasing a particular asset, a central bank reduces the amount of the security that the private sector holds, displacing some investors and reducing the holdings of others, while simultaneously increasing the amount of short-term, risk-free bank reserves held by the private sector. In order for investors to be willing to make those adjustments, the expected return on the purchased security has to fall. Put differently, the purchases bid up the price of the asset and hence lower its yield. This pattern was described by Tobin (1958, 1969) and is commonly known as the "portfolio balance" effect.[4]

Note that the portfolio balance effect has nothing to do with the expected path of short-term interest rates. Longer-term yields can be parsed into two components: the average level of short-term risk-free interest rates expected over the term to maturity of the asset and the risk premium. The former represents the expected return that investors could earn by rolling over short-term risk-free investments, and the latter is the expected additional return that investors demand for holding the risk associated with the longer-term asset. In theory, the effects of the LSAPs on longer-term interest rates could arise by influencing either of these two components. However, the Federal Reserve did not use LSAPs as an explicit signal that the future path of short-term risk-free interest rates would remain low.[5] In fact, at the same time that the Federal Reserve was expanding its

[4]There is a large body of literature on consumer optimizing models of portfolio selection, which are variants of the portfolio balance model that impose restrictions arising from the assumed (risk averse) utility functions of investors. See Markowitz (1952), Sharpe (1964), and Campbell and Viceira (2001, 2005). More recently, Vayanos and Vila (2009) have developed a theoretical model of the term structure based on preferred habitats of investors, which also relies on risk aversion. Andres, López-Salido, and Nelson (2004) provide an example of a dynamic stochastic general equilibrium model with imperfect asset substitutability based on frictions in financial markets.

[5]Indeed, the FOMC instead directly used language in its statements to signal that it anticipates that short-term interest rates will remain exceptionally low for an extended period. However, as discussed below, neither the language about future policy rates in the FOMC statements nor the LSAP announcements appear to have had a substantial effect on the expected future federal funds rate.

balance sheet through the LSAPs, it was going to great lengths to inform investors that it would still be able to raise short-term interest rates at the appropriate time. Thus, any reduction in longer-term yields instead has likely come through a narrowing in risk premiums.

For Treasury securities, the most important component of the risk premium is referred to as the "term premium," and it reflects the reluctance of investors to bear the interest rate risk associated with holding an asset that has a long duration. The term premium is the additional return investors require, over and above the average of expected future short-term interest rates, for accepting a fixed, long-term yield. The LSAPs have removed a considerable amount of assets with high duration from the markets. With less duration risk to hold in the aggregate, the market should require a lower premium to hold that risk. This effect may arise because those investors most willing to bear the risk are the ones left holding it.[6] Or, even if investors do not differ greatly in their attitudes toward duration risk, they may require lower compensation for holding duration risk when they have smaller amounts of it in their portfolios.

In addition to the effect of removing duration and hence shrinking the term premium across all asset classes, Federal Reserve purchases of agency debt and agency MBS might be expected to have an additional effect on the yields on those assets through other elements of their risk premiums. For example, these assets may be seen as having greater credit or liquidity risk than Treasury securities.[7] In addition, the purchases of MBS reduce the amount of prepayment risk that investors have to hold in the aggregate. Prepayment risk on MBS causes the duration of MBS to shrink when interest rates decline and rise when interest rates increase. These changes in duration imply that MBS have negative convexity: compared with the

[6]Indeed, in the preferred-habitat model of Modigliani and Sutch (1966) it is possible that some agents seek to hold long-duration assets—e.g., for retirement—so that the term premium can, in principle, be negative.

[7]Prior to December 2009, the Treasury had committed to sizable but limited capital injections in the housing agencies, and thus had not issued a blanket guarantee of agency obligations. On December 24, 2009, the Treasury removed the limit on capital injections over the next three years, stating that it wished to "leave no uncertainty about the Treasury's commitment to support these firms." Agency debt and agency MBS are not as liquid as Treasury securities. The direct effect of LSAPs on liquidity of these securities is considered further below.

price of a non-callable bond with the same coupon and maturity, MBS prices rise less when rates fall and decline more when rates rise. Given this undesirable profile and the cost of hedging against it, investors typically demand an extra return to bear the negative convexity risk, keeping MBS rates higher than they would otherwise be. The LSAPs removed a considerable amount of assets with high convexity risk, which would be expected to reduce MBS yields.

These portfolio balance effects should not only reduce longer-term yields on the assets being purchased but should also spill over into the yields on other assets. The reason is that investors view different assets as substitutes and, in response to changes in the relative rates of return, will attempt to buy more of the assets with higher relative returns. In this case, lower prospective returns on agency debt, agency MBS, and Treasury securities should cause investors to seek to shift some of their portfolios into other assets such as corporate bonds and equities and thus should bid up their prices. It is through the broad array of all asset prices that the LSAPs would be expected to provide stimulus to economic activity. Many private borrowers would find their longer-term borrowing costs lower than they would otherwise be, and the value of long-term assets held by households and firms, and thus aggregate wealth, would be higher.

The effects described so far would be caused by LSAP-induced changes in the stock of assets that is held by the public. Moreover, to the extent that investors care about expected future returns on their assets, today's asset prices should reflect expectations about the future stock of assets. Thus, a credible announcement that the Federal Reserve will purchase longer-term assets at a future date should reduce longer-term interest rates immediately. Otherwise, investors could make excess profits by buying the assets today to sell to the Federal Reserve in the future.

There may also be effects on the prices of longer-term assets if the presence of the Federal Reserve as a consistent and significant buyer in the market enhances market functioning and liquidity. The LSAP programs began at a point of significant market strains, and the poor liquidity of some assets weighed on their prices. By providing an ongoing source of demand for longer-term assets, the LSAPs may have allowed dealers and other investors to take larger positions in these securities or to make markets in them more actively, knowing that they could sell the assets if needed to the Federal Reserve.

Such improved trading opportunities could reduce the liquidity risk premiums embedded in asset prices, thereby lowering their yields.[8]

This liquidity, or market functioning, channel, which is distinct from the portfolio balance channel, appears to have been important in the early stages of the LSAP programs for certain types of assets. For example, the LSAP programs began at a point when the spreads between yields on agency-related securities and yields on Treasury securities were well above historical norms, even after adjusting for the convexity risk in MBS associated with the high interest rate volatility at that time. These spreads in part reflected poor liquidity and elevated liquidity risk premiums on these securities.[9] The flow of Federal Reserve purchases may have helped to restore liquidity in these markets and reduced the liquidity risk of holding those securities, thereby narrowing the spreads of yields on agency debt and MBS to yields on Treasury securities and reducing the cost of financing agency-related securities.

Another asset for which the market functioning channel was important in the early stages of the LSAP programs is older Treasury securities, which had become unusually cheap relative to more recently issued Treasury securities with comparable maturities.[10] Such differences would normally be arbitraged away, but investors and dealers were reluctant to buy the older securities because their poor liquidity meant that they might be difficult to sell. However, after the Federal Reserve began buying such bonds, the yield spreads narrowed to normal levels.

Overall, LSAPs may affect market interest rates through a combination of portfolio balance and market functioning effects. Although the effects on market functioning appear to have been important at the start of the LSAPs when financial markets were unusually

[8]It is possible that the flow of purchases may affect longer-term interest rates for reasons other than the effects on market functioning and liquidity, if the market faces other frictions.

[9]Another contributing factor to the high yield spreads is that many financial firms at that time faced constraints on their balance sheets, given the large capital losses on other assets and limited access to new funds. Capital constraints put agency-related debt at a disadvantage relative to Treasury securities, as agency-related holdings have a 20 percent risk weighting compared with 0 percent for Treasury securities.

[10]See Gürkaynak and Wright (2010, p. 56).

strained, the primary long-run effects are likely associated with the portfolio balance effect. The lack of significant movements in interest rates around the times that each component of the LSAP programs was wound down suggests that market functioning was no longer impaired and that the Federal Reserve presence in the market had little additional effect beyond that through its portfolio holdings.

3. Implementation of LSAPs

The Federal Reserve holds assets that it has purchased in the open market in its System Open Market Account (SOMA). Historically, SOMA holdings have been nearly all Treasury securities, although small amounts of agency debt were held at times in the past.[11] Purchases and sales of SOMA assets are called outright open-market operations (OMOs). Outright OMOs, in conjunction with repurchase agreements and reverse repurchase agreements, traditionally were used to alter the supply of bank reserves in order to influence conditions in the federal funds market.[12] Most of the higher-frequency adjustments to reserve supply were accomplished through repurchase and reverse repurchase agreements, with outright OMOs conducted periodically to accommodate trend growth in currency demand.

OMOs generally were designed to have a minimal effect on the prices of the securities included in the operations. To that end, they tended to be small in relation to the markets for Treasury bills and Treasury coupon securities. LSAPs, on the other hand, aimed to have a noticeable impact on the interest rates of the assets being

[11] Agency purchases were introduced in 1971 in order to "widen the base for System open market operations and to add breadth to the market for agency securities." New purchases were stopped in 1981, although some maturing funds from agency holdings were reinvested in newly issued agency securities. Beginning in 1997, all holdings of agency securities were allowed to mature without replacement. The last agency holding acquired under these programs matured in December 2003.

[12] A repurchase agreement is similar to a collateralized loan. The borrower sells a security to the lender and simultaneously promises to buy back the security at a fixed price. The Federal Reserve lends funds to the market through repurchase agreements in order to increase reserves. To withdraw funds, the Federal Reserve engages in repurchase agreements in the opposite direction, also known as "reverse repurchase agreements."

purchased as well as on other assets with similar characteristics. In order to achieve this goal, LSAPs were designed to be large relative to the markets for these assets. Between December 2008 and March 2010, the Federal Reserve purchased more than $1.7 trillion in assets. This represents 22 percent of the $7.7 trillion stock of longer-term agency debt, fixed-rate agency MBS, and Treasury securities outstanding at the beginning of the LSAPs.[13] Another way to scale the purchases is to measure the amount of duration they removed from the market using the concept of "ten-year equivalents," or the amount of ten-year par Treasury securities that would have the same duration as the portfolio of assets purchased. Between December 2008 and March 2010, the Federal Reserve purchased about $850 billion in ten-year equivalents. That represents more than 20 percent of the $3.7 trillion outstanding stock of ten-year equivalents across these three asset classes at the beginning of the programs.[14,15] We believe that no investor—public or private—has ever accumulated such a large amount of securities in such a short period of time.

Purchases of agency debt were concentrated in medium-term securities because of the small outstanding supply at longer maturities (figure 1). Purchases of agency MBS were concentrated in newly issued low-coupon thirty-year securities issued by Fannie Mae and Freddie Mac (figure 2), which were relatively more liquid and had longer durations than other MBS. Purchases of Treasury securities

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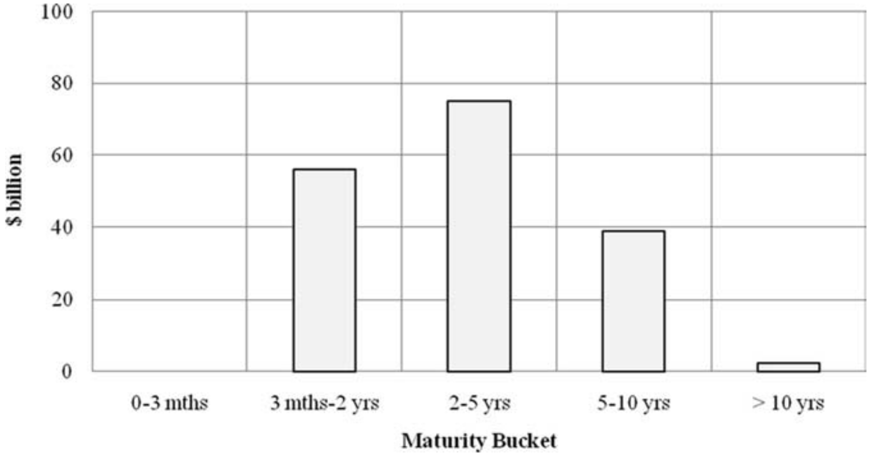
[13]The outstanding stock is computed from Barclays Capital Indices, based on data for November 24, 2008 (the day before the initial announcement of LSAPs). The amount includes only fixed-rate issues with at least one year to final maturity, and at least $250 million par amount outstanding. The measure of agency debt outstanding includes debt issued by U.S. government agencies, quasi-federal corporations, and corporate or foreign debt guaranteed by the U.S. government (such as USAID securities), but the largest issues are from Fannie Mae, Freddie Mac, and the Federal Home Loan Bank System.

[14]The outstanding stock of ten-year equivalents is also computed from Barclays Capital Indices, based on data for November 24, 2008. Note that this measure of duration is affected by changes in the shape of the Treasury yield curve and by the level of interest rates through their effect on prepayment of MBS.

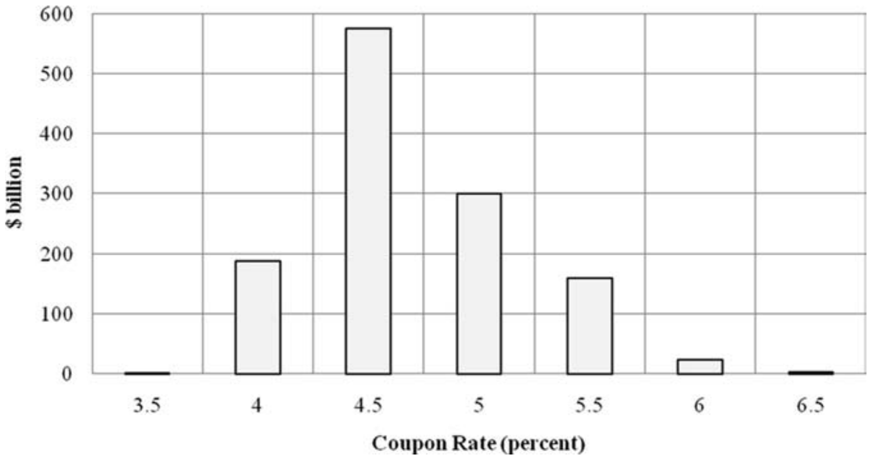
[15]Note that, in these calculations, we combine the purchases of all three asset types, as they all remove duration from the market and hence should affect risk premiums on all assets with duration exposure. In the regression analysis in section 4, we focus on the net supply of long-term assets by the public sector because this measure plausibly may be assumed to be exogenous with respect to risk premiums. We thus ignore privately issued long-term assets that are held by private investors.

Figure 1. Distribution of Agency Debt Purchases by Maturity



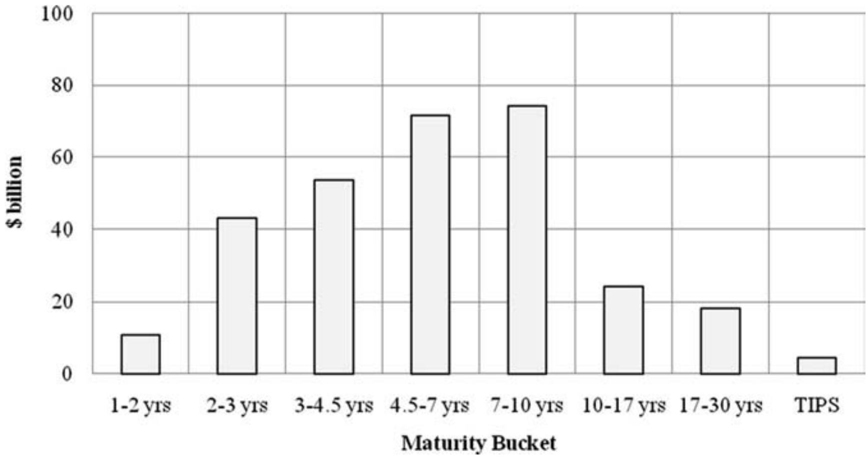
Source: Federal Reserve Bank of New York.

Figure 2. Distribution of MBS Purchases by Coupon



Source: Federal Reserve Bank of New York.

Figure 3. Distribution of Treasury Purchases by Maturity



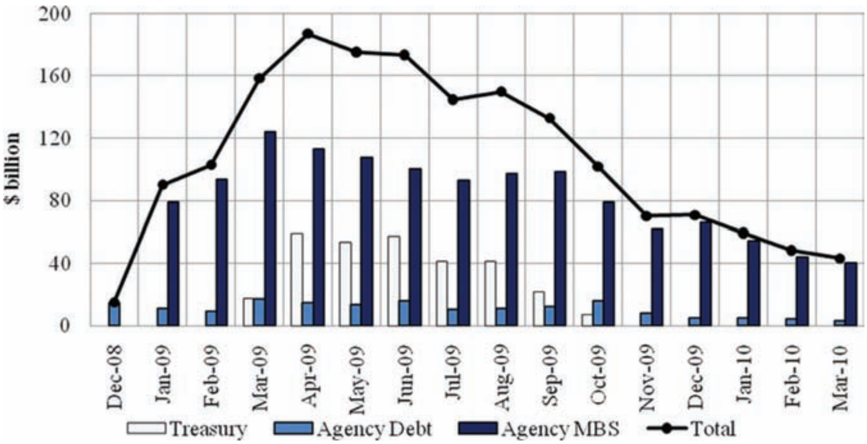
Source: Federal Reserve Bank of New York.

were concentrated in the two- to ten-year maturity sectors (figure 3). Nevertheless, there were significant amounts purchased outside of these targeted sectors, including a range of maturities of Treasury debt and higher-coupon seasoned agency MBS, in order to avoid substantial distortions in the yield curves and spreads on these assets. As noted earlier, purchases of agency debt and MBS began at a time when liquidity in these markets was poor and spreads to Treasury yields were unusually wide. In these circumstances, LSAPs appeared to improve market liquidity. Spreads of agency debt and MBS yields narrowed relative to Treasury yields, and spreads between on-the-run and off-the-run Treasury securities also narrowed.

The pace of purchases evolved fairly smoothly over the course of the program. Total purchases ranged between $50 and $200 billion on a monthly basis (figure 4). Purchases were somewhat heavier from March 2009 through June 2009, reflecting the expansion of the LSAP programs at that time and the large amount of MBS purchases made to offset heavy origination activity. The decision to taper purchases led to a slowing pace of purchases after the middle of 2009.[16]

[16]The decision to gradually slow the pace of Treasury purchases was announced in the August 2009 FOMC statement. The decision to gradually slow the pace of agency purchases was announced in the September 2009 FOMC statement.

Figure 4. Pace of Purchases by Asset Class



Source: Federal Reserve Bank of New York.

The Federal Reserve released a press statement shortly after the initial announcement of each program providing further details about the timing and overall structure of each program. Documents providing answers to frequently asked questions were released at the start of each program. These documents provided details as to what types of securities were eligible for purchase and what investment strategy would be employed, and they were updated to reflect changes in the programs, such as the increase in the targeted size of the agency debt and MBS programs or the inclusion of on-the-run securities for purchase in the agency debt program.

4. Estimates of LSAP Effects

4.1 Other Studies

According to the expectations theory of the term structure, altering the maturity of the net supply of assets from the government to private investors should have only minimal effects on the term structure of interest rates. This view was supported by the literature studying Operation Twist in the early 1960s, which did not find robustly significant effects of a swap between short-term and long-term Treasury securities in the SOMA portfolio.[17] However, as noted by Solow and Tobin (1987), Federal Reserve purchases during Operation Twist were small and were soon more than offset by increased Treasury issuance of long-term debt. Overall, there was little movement in the average maturity of Treasury debt held by the public and thus little hope of estimating a statistically significant and robust effect.

Subsequent time-series studies, using longer spans of data, generally have found a noticeable effect of shifts in the maturity structure of Treasury debt on the term structure.[18] The estimated size of this effect depends on the degree of theoretical restrictions imposed on the estimating equation. Tighter restrictions implied by simple models of household behavior generally lead to smaller estimates, but these restrictions typically are rejected statistically in favor of less restrictive specifications. Other time-series studies, while not focusing on the maturity structure of public debt, have found that increases in the total supply of public debt tend to raise longer-term interest rates.[19] Kozicki, Santor, and Suchanek (2010) analyze time-series data on the size of central bank balance sheets and find that increases in the balance sheet are associated with declines in long-term forward interest rates. Stroebel and Taylor (2009) find little effect of daily Federal Reserve purchases on the spread between MBS yields and swap yields and a moderate effect on the spread between MBS yields and Treasury yields.

[17]See, for example, Modigliani and Sutch (1967). The current program differs from Operation Twist in that the reduction in long-term bonds is financed by reserve creation rather than sales of short-term Treasury bills. However, with interest rates on bank reserves and short-term bills roughly equal in the current environment, the two assets should be viewed as close substitutes and thus the effect on the term spread should be similar.

[18]All of the studies focused on the United States. See Friedman (1981), Frankel (1985), Agell and Persson (1992), Kuttner (2006), and Greenwood and Vayanos (2010). Since the original draft of this paper was written, Hamilton and Wu (2010) estimated the model of Vayanos and Vila (2009) and obtained results broadly similar to ours.

[19]See Gale and Orszag (2004), Engen and Hubbard (2005), and Laubach (2009). Warnock and Warnock (2009) also find that purchases of U.S. debt by foreign governments tend to lower U.S. long-term interest rates.

Bernanke, Reinhart, and Sack (2004) adopt an alternative approach to time-series analysis. They examine specific news events concerning future Treasury issuance or purchases of longer-term securities and find that longer-term yields dropped significantly on days in which the market learned of future declines in the net supply of longer-term Treasury securities.

Since the original draft of this paper was written, two new papers have focused on the effects of the LSAPs. Neely (2010) uses the event-study methodology and shows that Federal Reserve announcements concerning LSAPs had significant effects on U.S. and foreign bond yields and on exchange rates. D'Amico and King (2010) use cross-section data on yields on all outstanding Treasury securities. They find that yields on securities purchased in the LSAP program fell more than yields on securities that were not purchased. Their model allows for own-price and cross-price effects on yields and they conclude that the program substantially reduced medium- and long-term Treasury yields. In addition to this permanent effect, they also find a small temporary effect of the flow of Federal Reserve purchases on yields.

In this paper, we employ both time-series and event-study methodologies to gauge the overall effects of the LSAP programs.

4.2 An Event Study of Recent LSAP Communications

In this section we use an event-study analysis of Federal Reserve communications to derive estimates of the effects of LSAPs. In particular, we examine changes in interest rates around official communications regarding asset purchases, taking the cumulative changes as a measure of the overall effects. In doing so, we implicitly assume that (i) our event set includes all announcements that have affected expectations about the total future volume of LSAPs, (ii) LSAP expectations have not been affected by anything other than these announcements, (iii) we can measure responses in windows wide enough to capture long-run effects but not so wide that information affecting yields through other channels is likely to have arrived, and (iv) markets are efficient in the sense that all the effects on yields occur when market participants update their expectations and not when actual purchases take place.[20]

The financial variables we examine are the two-year and ten-year Treasury yields, the ten-year agency debt yield, the current-coupon thirty-year agency MBS yield, the ten-year Treasury term premium (based on Kim and Wright 2005), the ten-year swap rate, and the Baa corporate bond index yield.[21] Swap rates and corporate bond yields help us to gauge the extent to which news about LSAPs affected yields on assets that were not purchased by the Federal Reserve.

We focus on a narrow set of official communications, each of which contained new information concerning the potential or actual expansion of the size, composition, and/or timing of LSAPs. The eight announcements included in this "baseline" event set are as follows:

- the initial LSAP announcement on November 25, 2008, in which the Federal Reserve announced it would purchase up to

[20]These are strong assumptions. The need for them arises in part because we do not have a direct measure of expectations about the size of future LSAPs. With such a measure, we could use announcements to identify exogenous shocks to LSAP expectations. The corresponding yield responses could then be used to derive statistical estimates of the effects of changes in expectations and, from these, the total effects of LSAPs could be extrapolated. Such an approach is typical of studies of the effects of surprise changes to the target federal funds rate, using interest rate futures contracts to measure market expectations. A particular challenge in isolating the effects of LSAPs is that the announcements we identify are likely to have contained non-LSAP information relevant to yields, including policy measures and updates to the FOMC's economic outlook. As a result, it is impossible to draw a response window narrow enough to include only the effects of LSAPs.

[21]We measure agency debt yields using Freddie Mac's on-the-run fixed-rate senior benchmark non-callable note; as of February 1, 2010, Fannie Mae had not issued a ten-year note since 2007. On-the-run agency debt was not included in LSAPs until September 2009, but the cumulative changes in the first off-the-run yield are almost identical to the changes in the on-the-run yield. The MBS yield is the average of the Freddie Mac and Fannie Mae current-coupon thirty-year agency MBS yields. The interest rates are from Bloomberg, except for the Baa yield, which is from Barclays Capital. The Kim-Wright term premium data are made available by the Federal Reserve Board at www.federalreserve.gov/econresdata/researchdata.htm. The Kim-Wright term premium is based on implied zero-coupon yields on off-the-run securities, whereas the Treasury yield series are for on-the-run coupon securities.

$100 billion in agency debt and up to $500 billion in agency MBS;
- Chairman Bernanke's December 1, 2008 speech, in which he stated that in order to influence financial conditions, the Federal Reserve "could purchase longer-term Treasury securities... in substantial quantities";
- the December 2008 and January 2009 FOMC statements, which indicated that the FOMC was considering expanding purchases of agency securities and initiating purchases of longer-term Treasury securities;
- the March 2009 FOMC statement, in which the FOMC announced the decision to purchase "up to" $300 billion of longer-term Treasury securities and to increase the size of agency debt and agency MBS purchases to "up to" $200 billion and $1.25 trillion, respectively;
- the August 2009 FOMC statement, which dropped the "up to" language qualifying the maximum amount of Treasury purchases and announced a gradual slowing in the pace of these purchases;
- the September 2009 FOMC statement, which dropped the "up to" language qualifying the maximum amount of agency MBS purchases and announced a gradual slowing in the pace of agency debt and MBS purchases; and
- the November 2009 FOMC statement, which stated that the FOMC would purchase "around $175 billion of agency debt."

We consider the response of interest rates using one-day windows around the announcements, measured from the closing level the day prior to the announcement to the closing level the day of the announcement.[22] Selecting the window length involves a trade-off between allowing sufficient time for revised expectations to become fully incorporated in asset prices and keeping the window narrow enough to make it unlikely to contain the release of other important information. Although event studies often examine *intraday* price changes in order to avoid the pollution of measured responses by

[22]We use the two-day change for the MBS yield around the March 2009 FOMC meeting because of an error in the Bloomberg MBS yield series on March 18. As discussed below, we also tried using two-day windows for all event days and interest rates.

Table 1. Interest Rate Changes around Baseline and Extended Event Set Announcements

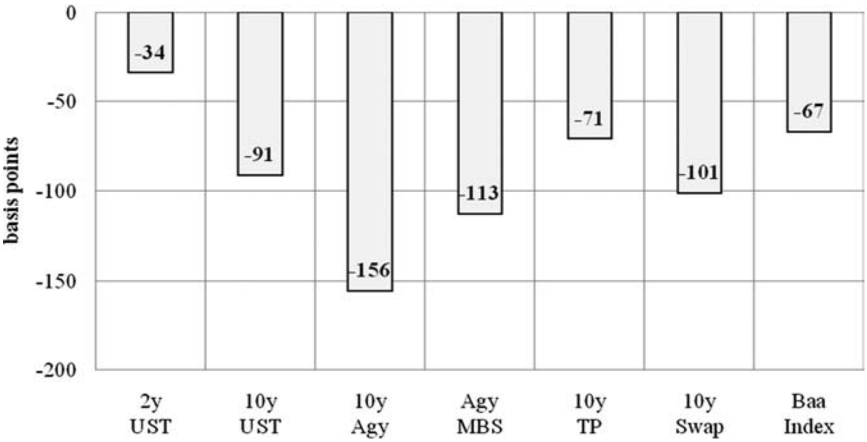
Date	Event	2y UST	10y UST	10y Agy	Agy MBS[b]	10y TP	10y Swap	Baa Index
11/25/2008[a]	Initial LSAP Announcement	−2	−22	−58	−44	−17	−29	−18
12/1/2008[a]	Chairman Speech	−8	−19	−39	−15	−17	−17	−12
12/16/2008[a]	FOMC Statement	−9	−26	−29	−37	−12	−32	−11
1/28/2009[a]	FOMC Statement	10	14	14	11	9	14	2
3/18/2009[a]	FOMC Statement	−22	−47	−52	−31	−40	−39	−29
4/29/2009	FOMC Statement	1	10	−1	6	6	8	−3
6/24/2009	FOMC Statement	10	6	3	2	4	4	5
8/12/2009[a]	FOMC Statement	−2	5	4	2	3	1	2
9/23/2009[a]	FOMC Statement	1	−3	−3	−1	−1	−5	−4
11/4/2009[a]	FOMC Statement	−2	6	8	1	5	5	3
12/16/2009	FOMC Statement	−2	1	0	−1	1	1	−1
1/27/2010	FOMC Statement	11	3	4	4	1	3	1
3/16/2010	FOMC Statement	−3	−5	−4	−4	−4	−4	−5
1/6/2009	Minutes Release	0	−4	3	−17	−1	−9	−14
2/18/2009	Minutes Release	9	11	4	6	8	9	16
4/8/2009	Minutes Release	2	−4	−7	−9	−4	−6	−6
5/20/2009	Minutes Release	−5	−5	−5	−7	−4	−4	−10
7/15/2009	Minutes Release	7	13	16	16	10	16	7
9/2/2009	Minutes Release	−1	−6	−6	−4	−7	−8	−5
10/14/2009	Minutes Release	1	7	10	3	7	7	8
11/24/2009	Minutes Release	0	−5	−5	−9	−5	−6	−3
1/6/2010	Minutes Release	−2	6	5	4	6	7	−1
2/17/2010	Minutes Release	4	7	7	8	6	8	5
Baseline Event Set		***−34***	***−91***	***−156***	***−113***	***−71***	***−101***	***−67***
Baseline Set + All FOMC		***−1***	***−55***	***−134***	***−114***	***−47***	***−75***	***−72***
Cumulative Change: 11/24/08 to 3/31/2010		***−19***	***50***	***−75***	***−95***	***30***	***28***	***−489***
Std Dev of Daily Changes: 11/24/08 to 3/31/10		***5***	***8***	***9***	***10***	***6***	***9***	***7***

[a]Included in the baseline event set.
[b]Two-day change for agency MBS on March 18, 2009 due to a Bloomberg data error.

extraneous information, we believe a wider window is suitable in this context. Specifically, given the novelty of the LSAPs and the diversity of beliefs about the mechanisms by which they operate, changes may have been absorbed more slowly than for typical monetary policy shocks (such as those to the target federal funds rate).

Table 1 displays the changes in interest rates on each day in the baseline event set described above as well as on days in which the

Figure 5. Cumulative Interest Changes on Baseline Event Set Days

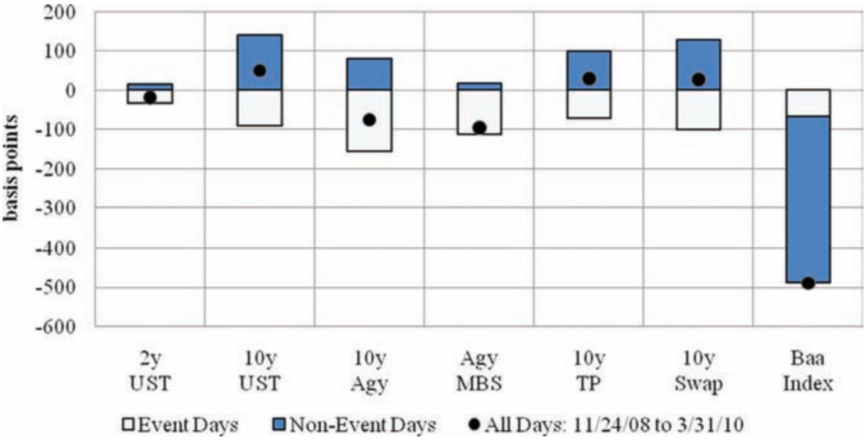


Source: Bloomberg, Barclays Capital.

FOMC issued communications concerning the LSAPs that provided little new information. Figure 5 displays the cumulative changes in interest rates across the eight announcements in the baseline event set. All interest rates declined notably, with the ten-year Treasury yield, ten-year agency debt yield, and current-coupon agency MBS yield declining 91, 156, and 113 basis points, respectively. The large change in the ten-year Treasury yield relative to the two-year Treasury yield suggests that the announcements reduced longer-term rates principally by reducing the term premium, as opposed to signaling a commitment to keep policy rates low for an extended period of time. This inference is confirmed by the large cumulative drop in the Kim-Wright ten-year term premium measure. The relatively large changes in agency debt and agency MBS yields demonstrate that the LSAPs also helped to lower spreads of the yields on these assets relative to those on Treasury securities. The substantial declines in the swap rate and the Baa corporate bond yield show that LSAPs had widespread effects, beyond those on the securities targeted for purchase.

Some observers, noting that the ten-year Treasury yield did not decline on net over the course of the LSAP programs, have argued

Figure 6. Cumulative Changes since November 2008, Event vs. Non-Event Days

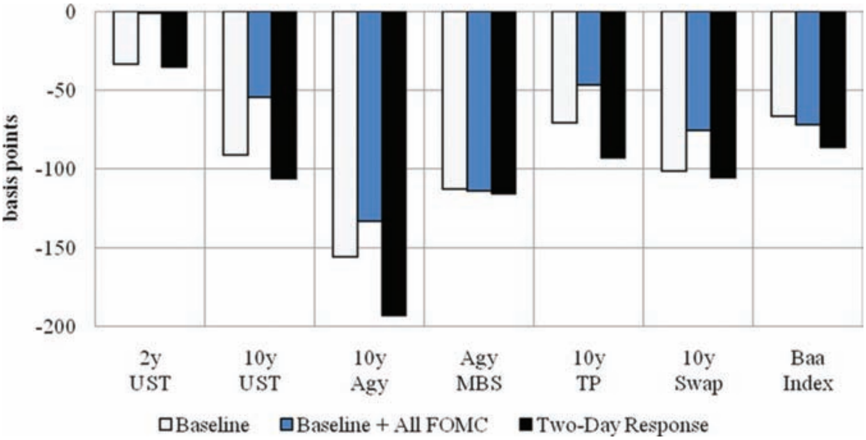


Source: Bloomberg, Barclays Capital.

that the LSAPs did not have a lasting effect. Figure 6 compares the net changes in interest rates on the baseline event days with the net changes on all other days from November 24, 2008 through March 31, 2010. The ten-year Treasury yield and swap rate increased more than 100 basis points on non-event days, and hence were up moderately over the entire period. However, there were many factors at play that would have been expected to lift Treasury yields over that period, including a very large increase in the expected future fiscal deficit, a significant rebound in the economic outlook, and a sharp reversal of the flight-to-quality flows that had occurred in the fall of 2008.[23] It is likely those factors, and not a reversal of the effects of the LSAP announcements, that drove Treasury yields higher on other days. Supporting that view, other interest rates showed very

[23]On December 10, 2008, the Blue Chip Economic Indicators survey average projection of the fiscal year 2009 federal deficit was $672 billion. In January 2010, the Congressional Budget Office estimated the 2009 deficit at $1587 billion and projected the 2010 deficit at $1381 billion. The Conference Board's Index of Leading Economic Indicators rose from 99.2 in November 2008 to 109.4 in March 2010.

Figure 7. Cumulative Interest Rate Changes around Announcement Events, Alternative Event-Study Parameters



Source: Bloomberg, Barclays Capital.

different patterns than that of the ten-year Treasury yield on non-event days. The agency debt yield rose less than the Treasury yield, the MBS yield was little changed, and the Baa corporate bond yield dropped about 400 basis points. This combination of a rising Treasury yield and a falling corporate bond yield is consistent with the relaxation of the extreme financial strains and flight to quality that characterized the early part of 2009, and it highlights the importance of focusing on event days to measure the effects of LSAPs separately from the effects of other developments.

Finally, figure 7 plots cumulative interest rate changes using two modifications to our event study. In the first, we continue to use one-day response windows but expand the event set to include all FOMC statements and minutes between November 2008 and January 2010 to allow for the possibility that markets gleaned information about the future of LSAPs from these communications. In the second, we use the same baseline event set as above but extend the response window to two days to allow for lagged reactions to the news by some market participants. Most of the measured effects of the LSAPs change only modestly using these alternative parameterizations of the event study. Using the expanded event set, the cumulative declines are between 10 basis points larger and 30 basis points smaller than with the baseline set. The smaller declines may reflect that markets had attributed some probability to further increases in the LSAPs and that these expectations were adjusted downward when the FOMC did not move in that direction on the non-baseline event days. On the other hand, using two-day response windows, the cumulative declines are 0 to 40 basis points larger than with the one-day windows, suggesting that it may have taken more than one day for the market to fully adjust to these communications.[24]

To more carefully evaluate whether the effects found above arose through the term premium, as would be expected from the theoretical discussion in section 2, we focus on yield movements around the two FOMC announcements that also contained new language on the prospects for future short-term interest rates. In particular, on December 16, 2008, the FOMC stated its view that the federal funds rate was likely to remain at "exceptionally low levels for some time." On March 18, 2009, the FOMC modified this language to "exceptionally low levels for an extended period." We want to make sure that the yield movements around those dates do not reflect a decline in expected future short-term interest rates associated with those statements.

One way to approach this issue is to rely on the Kim-Wright estimated term premium used above to examine the market interest rates with maturities that are most likely to be affected by the FOMC statements concerning the future federal funds rate. Any movement in the expected federal funds rate at these horizons is likely to be much greater than the average movement in the expected federal funds rate over the next ten years. We focus on the movement in the estimated one-year-ahead instantaneous interest rate around the release of the FOMC statements.[25] According to the Kim-Wright estimates, the one-year-ahead expected instantaneous interest rate dropped only 4 basis points on December 16, 2008 and then rose

[24]MBS yields, in particular, may have taken longer to respond fully to these communications. Adding a third day to the windows increases the cumulative decline of MBS yields by more than 30 basis points, whereas it has little effect on the cumulative declines in the other yields.

[25]The instantaneous interest rate is a construct of the Kim-Wright model that is essentially equivalent to the federal funds rate.

16 basis points the following day.[26] An alternative gauge of market expectations is the one-year-ahead forward instantaneous interest rate, as the term premium would presumably be limited in size at this horizon.[27] This rate dropped 11 basis points on December 16 but then rose 17 basis points the following day.

On March 18, 2009, the Kim-Wright one-year-ahead expected instantaneous interest rate dropped 4 basis points and rose by the same amount on the following day.[28] The one-year-ahead forward instantaneous rate dropped 28 basis points on March 18, but about half of this decline was unwound over the next few days. Overall, these observations on expected future and forward interest rates suggest that the December 2008 and March 2009 FOMC statements did not have large effects on market expectations of the future path of the federal funds rate—certainly not enough to explain the substantial decline in longer-term interest rates on those days.[29]

In principle, the LSAP programs could have raised the expected future path of the federal funds rate by accelerating the expected pace of economic recovery. In this case, the LSAP effect on the term premium would be greater than the effect on the long-term Treasury yield. According to table 1, however, the LSAP effects on the ten-year Treasury yield are slightly larger than those on the ten-year term premium, suggesting that LSAPs did not raise the expected future federal funds rate.

Altogether then, we find that longer-term interest rates declined by up to 150 basis points around key LSAP announcements. Moreover, the majority of the decline in the ten-year Treasury yield around these announcements can be attributed to declines in the term premium. Figure 7 shows that, depending on the event set

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[26]The two-year-ahead expected instantaneous interest rate dropped 6 basis points on December 16 and rose 4 basis points on December 17.

[27]The forward rate is the sum of the expected future instantaneous rate and the forward term premium. It can be derived directly from the yield curve without requiring any modeling of, or assumptions about, its components beyond those required to fit a yield curve to observed bond yields.

[28]The two-year-ahead expected instantaneous interest rate dropped 14 basis points on March 18 and rose 3 basis points on March 19.

[29]It is possible that these FOMC statements affected the term premium directly by reducing uncertainty about the path of future interest rates. Estimating this effect is beyond the scope of this paper, but we believe such effects are likely to have been small.

and response window used, LSAP announcements reduced the ten-year term premium by between 50 and 100 basis points. Little of the observed declines in longer-term yields appears to reflect declining expectations of future short-term interest rates associated with FOMC communications about the likely future path of the federal funds rate.

4.3 Time-Series Analysis of Longer-Term Treasury Supply

In this section, we use a different method and different data to measure the impact of asset purchases (or sales) on the ten-year term premium.[30] Specifically, we estimate statistical models that explain the historical variation (prior to the announcement of the LSAP programs) in the term premium using factors related to (i) the business cycle, (ii) uncertainty about economic fundamentals, and (iii) the net public-sector supply of longer-term dollar-denominated debt securities. Using a variety of model specifications, we estimate the effects of changes in the stock of longer-term debt held by private investors on the term premium. We then use these results to estimate the (out-of-sample) impact of the Federal Reserve's asset purchases, which represent a reduction in the supply of longer-term debt securities to private investors.

Following Backus and Wright (2007), we explain historical time variation in the term premium using an ordinary least squares regression model of the form

$$tp_t^{10} = X_t\beta + \varepsilon_t,$$

where tp_t^{10} is the nominal ten-year yield term premium, and X_t is a set of observable factors.[31] However, we expand on the set of

[30]The term premium likely captures the largest component of the LSAPs' effects on private borrowing rates. However, as we highlighted in section 2, LSAPs also affected other components of risk premiums. The statistical models here do not attempt to estimate these other effects or the effects on term premiums at different horizons.

[31]Whereas Backus and Wright modeled the instantaneous *forward term premium* ten years ahead, we focus on the ten-year *yield term premium* because of our interest in the purchases' effects on longer-term interest rates.

explanatory variables used by Backus and Wright, focusing on the three types of variables noted above.[32]

In particular, the following variables are included to capture term premium variation related to the business cycle and fundamental uncertainty:

- *Unemployment gap*: measured as the difference between the unemployment rate and the Congressional Budget Office's estimate of the natural rate of unemployment.
- *Core CPI inflation*: a second measure of the macroeconomic state, the twelve-month change in core CPI, may also proxy for inflation uncertainty.[33]
- *Long-run inflation disagreement*: measured as the interquartile range of five- to ten-year-ahead inflation expectations, as reported by the Michigan Survey of Consumers.[34]
- *Six-month realized daily volatility of the on-the-run ten-year Treasury yield*: a proxy for interest rate uncertainty. We use this instead of option-implied volatility because it is available over a longer period.[35]

To capture the effects of changes in the net public-sector supply of longer-term debt securities, we use the following time series, each of which is expressed as a percent of nominal GDP:

- publicly held Treasury securities with at least one year to maturity, including securities held by private investors as well as those held by the Federal Reserve and by foreign official institutions;

[32]In early analysis we also included a measure of the on-the-run Treasury liquidity premium as a proxy for the "flight-to-quality" demand for Treasuries. However, the coefficient on this term was never significant, and excluding it did not affect the magnitude or significance of the other coefficients. For ease of exposition, we omit it here.

[33]Mankiw, Reis, and Wolfers (2004) show that inflation disagreement, the level of inflation, the absolute value of the change in inflation, and relative price variability positively co-vary.

[34]We use the Michigan survey because of its long history and relatively high frequency (monthly), but our results are not significantly affected if we use long-run inflation disagreement taken from the Blue Chip Economic Indicators survey instead. The Michigan survey did not include the long-run inflation question during some months during the 1980s. We linearly interpolate the series where data are missing.

[35]Realized and implied volatility are highly correlated at the monthly frequency, and our modeling choice does not appear to substantively alter the results.

- Treasury securities held in the Federal Reserve's SOMA portfolio with at least one year to maturity;[36] and
- U.S. debt securities held by foreign official agencies, with at least one year to maturity. This measure includes Treasury securities, agency-related securities, and corporate bonds, and is interpolated from annual stock surveys, using monthly Treasury International Capital (TIC) flows, by the Board of Governors of the Federal Reserve System.[37]

An important assumption of our statistical analysis is that these longer-term debt stock variables are exogenous with respect to the term premium. For example, this assumption implies that the Treasury does not issue more long-term debt when the term premium declines. To the extent that these public-sector agencies do respond to term premiums in a manner similar to private investors—that is, by buying more long-term debt (or selling less long-term debt) when the term premium is high—our estimates of the effect of public-sector longer-term debt supply on the term premium will be biased downward. Overall, we believe it is reasonable to assume that these public agencies respond very little to term premiums. However, our estimates may be viewed as somewhat conservative owing to this potential downward bias.

The response of private investors to the net public-sector supply of assets should not be affected by the specific public-sector agency doing the purchases or sales. Thus, when the Treasury buys back a longer-term security, it should have the same effect on longer-term yields as when the Federal Reserve buys that security or when a foreign official agency buys that security (assuming that each is expected to hold the security on a persistent basis and controlling for any policy signals the purchases convey). Moreover, the term premium should be roughly equally affected by public-sector purchases of either Treasury securities or agency-related securities with similar durations. Accordingly, the appropriate measure of the net supply of longer-term debt securities by the public sector would include

[36]As noted above, the SOMA held agency securities between 1971 and 2003. However, these were a very small portion of total SOMA holdings (less than 5 percent), and information on the maturity and duration of these holdings is not available.

[37]See Bertaut and Tryon (2007). The data are available at www.federalreserve.gov/pubs/ifdp/2007/910/default.htm.

longer-term Treasury securities less the total amount of longer-term debt held by the SOMA and by foreign official institutions.[38] We estimate models with this measure of the net supply of longer-term debt expressed in both unadjusted terms and as ten-year Treasury equivalents.[39] The duration adjustment captures relevant variation in the *composition* of the outstanding stock of debt securities.[40]

We estimate the model on monthly data over the period January 1985 to June 2008. This period was selected because it is the full sample over which data on each of the variables is available, and because it ends shortly before the initial announcement of asset purchases in the fall of 2008. The first two columns of table 2 present results from a regression of the ten-year term premium on the explanatory variables, using the unadjusted net debt stock measure. The third and fourth columns present results using the duration-adjusted net debt stock. For comparison, in this and subsequent tables, we include estimates from the model without any debt supply variable in the final columns.

The results are similar with either measure of the debt stock. The explanatory variables are almost all significant at the 1 percent level and always have the expected sign. Specifically, 1-percentage-point increases in the unemployment gap, core CPI inflation, inflation disagreement, and realized volatility increase the term premium about 20, 30, 40, and 100 basis points, respectively. As for the supply variables, a 1-percent-of-GDP increase in longer-term debt supply

[38]We do not include privately issued debt securities held by private investors because these securities have a net zero supply from the point of view of the private sector, and because demand and supply for them are likely not exogenous with respect to the term premium.

[39]The unadjusted stock of Treasury securities with remaining maturity greater than one year is obtained from table FD-5 of the *Treasury Bulletin*. This table excludes SOMA holdings but includes foreign official holdings, which we subtracted using the TIC data described above. The duration-adjusted stock of non-SOMA Treasuries comes from Barclays Capital and, unlike the unadjusted measure, excludes Treasury Inflation-Protected Securities (TIPS). In the duration-adjusted regressions we use foreign holdings of long-term Treasury securities only (i.e., not agency-related securities or corporate bonds) and assume that these have the same duration as non-SOMA Treasuries held by the public. Because we cannot isolate foreign holdings of TIPS, the adjusted stock variable may understate holdings (by subtracting TIPS holdings from a total stock measure that already excludes it). The effect should be minor.

[40]As described in section 2, the adjustment converts the amount, S, into an amount of ten-year Treasury securities with the same portfolio duration: ten-year equivalents = S $*$ duration(S)/duration(10y).

Table 2. OLS Regression of Ten-Year Term Premium, January 1985–June 2008

	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	−2.182***	0.348	−2.324***	0.349	−1.852***	0.334
Cyclical Factors						
Unemployment Gap	0.180**	0.064	0.185**	0.063	0.252***	0.070
Core CPI	0.307***	0.056	0.298***	0.057	0.480***	0.062
Uncertainty						
Inflation Disagreement	0.377**	0.131	0.394**	0.133	0.286*	0.123
Realized Volatility	0.943***	0.207	0.994***	0.206	0.944***	0.271
Supply						
Unadjusted	0.044***	0.009	—	—	—	—
Duration-Adjusted	—	—	0.064***	0.014	—	—
Adjusted R-squared	0.84		0.84		0.78	
Standard Error of Regression	0.36		0.37		0.43	
Number of Observations	282		282		282	

Notes: Newey West standard errors (twelve lags). ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

increases the ten-year term premium by 4.4 basis points on an unadjusted basis and 6.4 basis points when expressed in terms of ten-year Treasury equivalents.[41] Both coefficients are statistically significant at the 1 percent level.[42]

The $1.725 trillion in purchases by the Federal Reserve is roughly 12 percent of 2009 nominal GDP, which, according to the estimates in the first column, implies that total Federal Reserve asset purchases reduced the term premium by 52 basis points. In terms of ten-year equivalents, the Federal Reserve purchased a total of approximately $850 billion—roughly 6 percent of 2009 nominal GDP—which, according to estimates in the third column, would imply that asset purchases reduced the term premium by 38 basis points.

None of the variables included in the model can grow or decline without bound, and thus there is a strong presumption that they are stationary. However, some of them may have a sufficiently large autocorrelation to appear non-stationary within our twenty-three-year estimation sample. Thus, we also use dynamic ordinary least squares (DOLS) based on Stock and Watson (1993) to estimate the long-run relationship (also known as the cointegrating vector) between the term premium and the explanatory variables. In addition to the levels of our explanatory variables, the contemporaneous, lead, and lagged first differences of each are included as regressors.[43]

[41] We cannot reject that the debt stock coefficients are constant between the first and second halves of the sample.

[42] If the debt stock components—Treasury, SOMA, and TIC—are entered separately into the regression, the coefficients on SOMA and TIC are a bit larger and the coefficient on Treasury is considerably smaller than the coefficient on the combined variable. We suspect that the smaller separate Treasury estimate arises because shifts in the supply of long-term Treasury securities are anticipated far in advance. In the regressions reported here we nevertheless impose the assumption that the effects are the same.

[43] The following procedure was used to select the leads and lags included within the DOLS regression. We start with a single lead and lag of the first difference of each explanatory variable. If the lead or lag for a variable was statistically significant at the 5 percent level (using Newey-West standard errors with twelve lags), we added one more, and removed all leads and lags that were not significant. If the added lead or lag was still significant, we added four more. For each specification this was enough to make the leads and lags of the longest length statistically insignificant. For robustness, we also estimated the model using six leads and lags of the first differences. The coefficient estimates on supply in the cointegrating vectors were virtually unchanged from those derived according to the selection procedure just described.

The level coefficients from the DOLS regression estimate the long-run relationship between the variables, and the deviation of the term premium from this long-run relationship is referred to as the cointegration error. Regressing the change in the term premium on the contemporaneous change in the explanatory variables and on the lagged level of the cointegration error allows us to estimate the long-run adjustment speed of the cointegrating relationship and to test the significance of the cointegrating relationship.

The first two columns of table 3 present results from the DOLS model, again estimated over the period January 1985 to June 2008. The long-run effects of changes in the longer-term debt stock are almost identical to those obtained in table 2. Specifically, an increase in longer-term debt equal to 1 percent of GDP increases the term premium by just over 4 basis points in the unadjusted specification and by just over 6 basis points in the duration-adjusted specification. The adjustment speed parameters of −0.15 imply that deviations in the term premium from long-run equilibrium have a half-life of roughly five months. The t-statistics on the adjustment speeds are −5.7 and −6.3, which are sufficiently large to reject the hypothesis that these variables do not have a stable long-run relationship (that is, they are not cointegrated) at the 1 percent significance level. Note that the adjustment speed drops substantially when the debt stock variables are excluded (the final columns), suggesting that the longer-term debt stock is an important part of the long-run relationship.

The preceding regressions are based on the Kim-Wright model of the ten-year term premium, which was estimated over a sample that does not include a major financial crisis or monetary policy constrained by the zero bound on nominal interest rates. As a robustness check, we also estimate a specification that uses the ten-year Treasury yield as the dependent variable and that includes the target federal funds rate and the slope of the near-term Eurodollar futures curve to proxy for the expected path of policy rates.[44] Under the assumption that the two additional variables adequately control for expected future policy interest rates, the estimated coefficients on

[44]Specifically, we use the difference between the implied rates on Eurodollar futures contracts settling approximately two years and one year ahead.

Table 3. Dynamic OLS Regression of Ten-Year Term Premium, January 1985–June 2008

	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	−2.288***	0.388	−2.351***	0.425	−1.879***	0.355
Cyclical Factors						
Unemployment Gap	0.222***	0.062	0.219***	0.063	0.283***	0.071
Core CPI	0.302***	0.065	0.281***	0.063	0.502***	0.067
Uncertainty						
Inflation Disagreement	0.458**	0.173	0.454*	0.180	0.292	0.152
Realized Volatility	0.822***	0.221	0.901***	0.229	0.867**	0.296
Supply						
Unadjusted	0.042***	0.008	—	—	—	—
Duration-Adjusted	—	—	0.062***	0.014	—	—
Long-Run Properties						
Adjustment Parameter[a]	−0.154***	0.03	−0.151***	0.024	−0.116***	0.021
ADF Test on Coint. Error[b]	−6.051***		−5.957***		−3.441**	
Number of Observations	282		280		282	

Notes: Newey West standard errors (twelve lags). ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.
[a]Estimated by regressing the change in the term premium on the contemporaneous change in each explanatory variable and on the lagged level of the cointegration error.
[b]Null hypothesis: no cointegrating relationship.

the other variables should continue to reveal their impact on the ten-year term premium. Note that another reason for focusing directly on the behavior of the ten-year yield is that the ultimate goal of LSAPs is to lower longer-term private borrowing rates, many of which are highly correlated with ten-year Treasury yields. As the first and third columns of table 4 show, the estimated longer-term debt supply effects are somewhat higher in this specification than in the term premium regressions. The estimated coefficients of 0.07 and 0.10 on the unadjusted and duration-adjusted debt stocks imply that LSAPs have reduced the ten-year term premium by 82 basis points (unadjusted model) or 58 basis points (duration-adjusted model).[45]

Table 5 summarizes the estimated coefficients on longer-term debt stock across our specifications and lists the implied effects of the Federal Reserve's asset purchases on the ten-year term premium. Our results suggest that the $1.725 trillion in announced purchases reduced the ten-year term premium by between 38 and 82 basis points. This range of point forecasts overlaps considerably with that obtained in our event study, which is impressive given that entirely separate data and methodologies were used to obtain the results.[46]

5. Experiences of Other Countries with Large-Scale Asset Purchases

Central banks in Japan and the United Kingdom also have engaged in large-scale purchases of longer-term assets to provide greater monetary stimulus at times when the conventional monetary policy

[45]Using a longer sample and somewhat different specification, Greenwood and Vayanos (2010) also find a statistically significant effect of bond supply on the bond yields. They regress the spread of the five-year Treasury yield to the one-year Treasury yield and the spread of the twenty-year yield to the one-year yield on the ratio of Treasury securities with maturities greater than ten years to total Treasury securities. They do not subtract SOMA or TIC holdings. Over the period 1952–2005, they find that a 1-percentage-point increase in the share of Treasury securities with maturities above ten years increases the five-year yield spread 4 basis points and the twenty-year yield spread 8 basis points.

[46]The event-study range is somewhat higher than the time-series range. This difference may reflect that LSAP effects are larger when financial conditions are strained. Alternatively, it is possible that the effect of maturity supply on bond yields is non-linear, so that large reductions in net supply have a proportionally larger (or smaller) effect on yields. The LSAP programs constituted a large shift in maturity supply by historical standards.

Table 4. OLS Regression of Ten-Year Treasury Yield, December 1986–June 2008

	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	0.297	0.432	0.103	0.443	−0.013	0.513
Rate Expectations						
Target Federal Funds	0.403***	0.114	0.424***	0.118	0.742***	0.114
Eurodollar Slope	0.477*	0.214	0.478*	0.225	0.602*	0.273
Cyclical Factors						
Unemployment Gap	0.127	0.208	0.172	0.210	0.784***	0.198
Core CPI	0.378**	0.125	0.342**	0.131	0.163	0.157
Uncertainty						
Inflation Disagreement	0.210	0.165	0.215	0.170	0.111	0.187
Realized Volatility	1.057***	0.25	1.145***	0.27	1.340***	0.31
Supply						
Unadjusted	0.069***	0.014	—	—	—	—
Duration-Adjusted	—	—	0.098***	0.023	—	—
Adjusted R-squared	0.92		0.91		0.88	
Standard Error of Regression	0.45		0.46		0.53	
Number of Observations	259		259		259	

Notes: Newey West standard errors (twelve lags). ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

Table 5. Effect of 1-Percent-of-GDP Increase in Long-Term Debt and Total Effect of LSAPs on Ten-Year Term Premium (bps)

	OLS Term Premium Model	DOLS Term Premium Model[a]	Yield Level Model
Effect of 1-Percent-of-GDP Increase in Long-Term Debt on Ten-Year Premium (bps)			
Unadjusted	4.4	4.2	6.9
Duration-Adjusted	6.4	6.2	9.8
Total Effect of LSAPs on Ten-Year Term Premium (bps)			
Unadjusted	52	50	82
[95% CI]	[31 to 74]	[31 to 69]	[50 to 115]
Duration-Adjusted	38	36	58
[95% CI]	[22 to 54]	[20 to 53]	[31 to 84]

[a]Long-run effect.

interest rate was close to zero.[47] The effects on longer-term yields in Japan appear to have been small, reflecting the smaller scale of the purchases and the shorter maturities purchased. In the United Kingdom, where the purchases were of a similar scale and maturity to those in the United States, the effects on longer-term yields have been similar to those in the United States.

5.1 Japan, 2001–06

In March 2001, the Bank of Japan (BOJ) introduced the quantitative easing policy (QEP) to fight deflation. The main element of the QEP was to supply banks with more than sufficient liquidity to keep the overnight interest rate at zero and thus to encourage bank lending. A secondary element of the QEP was a commitment to maintain zero interest rates until the core consumer price inflation rate was sustainably above zero. Purchases of Japanese government bonds (JGBs) were a tertiary element of QEP, but the BOJ did not claim that purchases of JGBs would reduce longer-term interest rates. Rather, JGBs were viewed as an appropriate and convenient asset for the BOJ to buy in order to supply banks with liquidity.

Ugai (2007) reports that studies of the portfolio balance effect of JGB purchases under the QEP find either small or insignificant effects on longer-term interest rates, including on corporate bonds. Bernanke, Reinhart, and Sack (2004) also report only a small effect of news about JGB purchases on longer-term yields. Relatively small effects on yields probably reflect that the JGB purchases were not large as a share of GDP and that they were skewed toward bonds with short residual maturities. According to Ugai (2007), the peak increase in BOJ holdings of JGBs under the QEP was about 4 percent of GDP, considerably less than the 12 percent of GDP increase in Federal Reserve holdings under the LSAPs. McCauley and Ueda

[47]In May 2009, the European Central Bank (ECB) announced plans to purchase €60 billion of covered bonds, which have a range of maturities. Relative to euro-area GDP, this program is about one-twentieth the size of the U.S. and U.K. asset purchase programs, and its effects on longer-term interest rates are likely to be very small. In May 2010, the ECB announced plans to purchase sovereign bonds of its member countries in order to improve market depth and liquidity. The program was not aimed at lowering interest rates in general, and planned purchase amounts have not been announced.

(2009) show that the additional BOJ purchases were mainly seasoned JGBs with short residual maturities; the average maturity of the BOJ's holdings of JGBs fell from more than five years to less than four years under the QEP.[48] Moreover, the Ministry of Finance increased the average maturity of newly issued JGBs from five years in 2001 to six and a half years in 2005, further offsetting any effect of the QEP on longer-term bond yields.

5.2 United Kingdom, 2009–10

On February 11, 2009, Governor King of the Bank of England (BOE) stated at a press conference that "further easing in monetary policy may well be required." At that time the BOE's policy interest rate target was 1 percent. When asked about the scope for further easing so close to the zero lower bound, King said "we will be moving to a world in which we will be buying a range of assets, but certainly including gilts."[49] On March 5, the BOE lowered its policy rate target to 0.5 percent and announced plans to purchase £75 billion in assets, mainly gilts with residual maturities between five and twenty-five years. In contrast to the Federal Reserve's LSAP programs, which were adjusted only once, the BOE adopted a more active approach to adjusting its asset purchase program. On May 7 the program was expanded to £125 billion. On August 6 it was expanded to £175 billion. On November 5 it was expanded to £200 billion. On February 4, 2010, after the £200 billion target was reached, the BOE said it would cease additional purchases but would continue to monitor the appropriate scale of the program in light of the economic outlook.

The BOE gilt purchases, at 14 percent of U.K. GDP, were similar in scale to the Federal Reserve LSAPs, at 12 percent of U.S. GDP. According to table B in Joyce et al. (2010), the average yield on five- to twenty-five-year gilts fell 100 basis points in total during two-day windows surrounding the six announcement dates noted above. That

[48]Total BOJ holdings of JGBs increased about 45 percent from 2001 to 2005. If redemptions on the initial holdings are assumed to be replaced with JGBs of sufficient maturity to hold the average maturity of those holdings constant, then the additional JGB purchases under the QEP would have had an average maturity of less than one year.

[49]Joyce et al. (2010, p. 12).

decline is strikingly similar to the 106-basis-point decline in U.S. ten-year Treasury yields (using two-day windows around the baseline event set) shown in figure 7 of this paper. In both the U.K. and U.S. event studies, yields on one-year and two-year bonds fell very little, suggesting that expectations about the future policy interest rate were not responsible for most of the decline in longer-term yields.

Over the six announcement dates, U.K. investment-grade corporate yields fell 70 basis points and U.K. speculative-grade corporate yields fell 150 basis points. These declines are broadly comparable to the declines on similar classes of corporate bonds in the United States around the U.S. event dates. One puzzling difference between the U.S. and U.K. experiences is that ten-year swap rates fell only 10 basis points in the U.K. event windows whereas they fell 100 basis points in the U.S. event windows.[50]

6. Conclusion

With policy interest rates in many countries constrained by the zero bound, and with short-term interest rates in Japan having been near zero for over a decade, expanding the toolkit of monetary policy is an important objective. In this paper, we examined lessons from the experience of the Federal Reserve since late 2008 with one of the key policy tools available at the zero bound—large-scale purchases of longer-term assets.

By reducing the net supply of assets with long duration, the Federal Reserve's LSAP programs appear to have succeeded in reducing the term premium. The overall size of the reduction in the ten-year term premium appears to be somewhere between 30 and 100 basis points, with most estimates in the lower and middle thirds of this range. In addition to this reduction in the term premium, the LSAP programs had an even more powerful effect on longer-term interest rates on agency debt and agency MBS by improving market liquidity

[50]The U.K. swap rates in Joyce et al. (2010) are linked to the sterling overnight index average (SONIA) rate whereas the U.S. swap rates in this paper are linked to the three-month LIBOR. U.S. ten-year swap rates based on the overnight federal funds rate fell 50 basis points in two-day windows around our baseline event dates.

and by removing assets with high prepayment risk from private portfolios. Similar effects appear to have occurred in the United Kingdom after the Bank of England launched a broadly similar LSAP program in 2009.

Based on this evidence, we conclude that the Federal Reserve's LSAP programs did lower longer-term private borrowing rates, which should stimulate economic activity. While the effects are especially noticeable in the mortgage market, they appear to be widespread, including in the markets for Treasury securities, corporate bonds, and interest rate swaps. That conclusion is promising, as it means that monetary policy remains potent even after the zero bound is reached. To be sure, achieving this further stimulus was not without its challenges, as it required a sizable expansion of the Federal Reserve's balance sheet, and the purchase of such a large volume of securities in a relatively short time frame required surmounting some operational hurdles. However, by restoring functioning to the mortgage market and lowering the term premium, the programs provided considerable benefits.

Even though the LSAPs appear to have been successful, it is worth reflecting on their structure and considering whether the approach taken was optimal. The LSAPs, as implemented, were discrete in nature, in that the broad characteristics of the programs were set in two decisions upfront (in November 2008 and March 2009). The remainder of the programs involved carrying out those decisions, with little responsiveness to changes in the economic or financial outlook.

By stating a specific amount and a timetable for LSAPs upfront, the FOMC appeared to commit itself to a future course of action. This commitment was softened somewhat by the use of the phrase "up to" before the specified purchase amounts. However, market participants generally indicated that they expected the full amounts to be purchased, and in the later stages of the programs the FOMC made it clear that close to the full amounts would be purchased. Policymakers often prefer not to make strong commitments on future policies because there is always a chance that future economic conditions will call for a different policy stance than expected. Policymakers may want to assess the benefits of this element of commitment relative to an approach that instead allows greater responsiveness to economic and financial conditions. Bullard (2009) lays out the theoretical case for a policy rule for LSAPs analogous to conventional policy rules for interest rates, but he shows that the practical issues in designing such a rule are substantial, particularly in light of the limited historical experience of economies operating near the zero bound on nominal interest rates.[51] Clearly, study of both the theoretical and empirical issues raised by LSAPs would be helpful in order to assess whether they can be employed even more effectively in the future.

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[51] An alternative strategy, proposed by Bernanke (2002), is to use unlimited purchases to target near-zero yields on Treasury securities with successively longer maturities, starting with one-year securities. This strategy entails a completely elastic response of LSAPs to interest rates on the targeted securities but leaves open the question of how to relate the choice of targeted maturities to economic conditions.

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Discussion of “The Financial Market Effects of the Federal Reserve’s Large-Scale Asset Purchases”

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1. Introduction

It is now one of the most important tasks in the area of monetary policy research to empirically evaluate the effectiveness of the monetary policy operations adopted by the central banks facing the zero lower bound. In this paper, Gagnon et al. (2011) empirically investigate the impacts of the Federal Reserve’s program called large-scale asset purchases (LSAPs). They conduct two types of empirical exercises for this purpose: the event-study analysis and the time-series analysis. They find through the event-study analysis that the LSAPs of $1.7 trillion lowered the ten-year Treasury yield by 62 basis points, and that the ten-year agency debt yield and the mortgage-backed securities (MBS) yield declined more. They also find through the time-series analysis using the data over 1985 to 2008 that the LSAPs lowered the ten-year Treasury yield by 52 basis points. They also provide some evidence that the decline in the long-term interest rate reflects lower risk premiums, rather than lower expectations about future short-term interest rates.

The ultimate purpose of the paper is to know whether the LSAPs program worked or not. In the simplest way, their answer is, “Yes, it worked.” But my first reaction was how large the number like “62 basis points” is, and whether this decline was sufficiently large to improve conditions in the U.S. credit markets. In my discussion, I will try to think about the economic meaning of their estimates. But before going to detailed comments, let me briefly mention the unique feature of this paper. This is surely one of the pioneering papers on this issue, but there are already several papers that seek to evaluate the effectiveness of the Federal Reserve's policy during the recent crisis, including Hamilton and Wu (2010) and Doh (2010), although their number is still limited.

What I found to be quite unique about the paper is its description about cross-country comparison of large-scale asset purchases by the other two central banks: the Bank of Japan (BOJ) and the Bank of England. Unfortunately, their cross-country analysis is at a very early stage, so that I was not able to learn much about the similarities and differences between the Federal Reserve's LSAPs and, for example, the quantitative easing program adopted by the BOJ in 2001–06. I look forward to seeing a more comprehensive and detailed cross-country comparison either by the authors or by someone else. Another unique feature of the paper is its description about how the LSAPs were implemented. Section 3 of the paper tells about the core ideas of the LSAPs program that were shared by the staff of the Federal Reserve involved in the operation.[1]

2. LSAPs vs. Standard Monetary Easing

The authors report several numbers related to the effectiveness of the LSAPs. For example, they report through the times-series analysis that the LSAPs of $1.7 trillion lowered the ten-year Treasury yield by 52 basis points. This does not look like a small number, but I still wonder how large this is. The natural and easiest way to know how large this is will be to compare this number with the corresponding number associated with an interest rate cut in the normal circumstance (i.e., the policy rate is not at the zero lower bound).

Simulation results using the FRB/US model indicate that a 100-basis-point shock to the federal funds rate changes the ten-year Treasury yield by 15 basis points. This implies that we need to cut the federal funds rate by 350 basis points to achieve a decline of the ten-year Treasury yield by 52 basis points. In other words, the

[1]Gagnon et al. (2010), the working paper version of this paper, provides a more extended discussion of the LSAPs' implementation and gave me a sense of really being there (i.e., at the operation desk of the Federal Reserve Bank of New York).

impact of the LSAPs of $1.7 trillion, or 12 percent of nominal GDP, is almost the same as that of a reduction of the federal funds rate by 350 basis points. Of course, that cut of the federal funds rate is not feasible because of the zero lower bound, but this translation exercise gives us a clearer idea about the magnitude of the effects of the LSAPs. For example, I can now imagine, based on various empirical evidences on monetary easing in Japan, that the impact of the LSAPs was probably much larger than that of the quantitative easing program conducted by the BOJ.

However, it should be noted that a reduction of the federal funds rate by 350 basis points is not extraordinarily large. For example, the federal funds rate declined more than 500 basis points during monetary easing in 2001–04, and more than 600 basis points during monetary easing in 1989–93. Compared with these numbers, the impact of the LSAPs seems to be modest. According to the Federal Open Market Committee (FOMC) statement in March 2009, the purpose of the LSAPs is to "help improve conditions in private credit markets" and to "provide greater support to mortgage lending and housing markets." Whether the LSAPs had sufficiently large impacts in light of these policy objectives still remains unclear.

3. Unconventional Monetary Operations

The descriptions in section 3 about the distinction between conventional and unconventional monetary policy are informative. On the one hand, conventional open-market operations (OMOs) are characterized by two principles: a central bank buys and sells only Treasury securities, and seeks to minimize effects of those transactions on market prices. As for the second feature, Gagnon et al. (2011) describe OMOs at the Federal Reserve as follows: "OMOs generally were designed to have a minimal effect on the prices of the securities included in the operations" (p. 10) and OMOs "tended to be small in relation to the markets for Treasury bills and Treasury coupon securities" (p. 10). On the other hand, OMOs in the LSAPs program are characterized by much wider varieties of securities, and OMOs in the LSAPs program "aimed to have a noticeable impact on the interest rates of the assets being purchased" (p. 10), and were "designed to be large relative to the markets for these assets" (p. 11).

This distinction between conventional and unconventional monetary operations is very clear.

At the same time, the authors describe some features of the operations actually conducted by the Federal Reserve. For example, in Gagnon et al. (2010), they state that "purchases of MBS were concentrated in newly issued, thirty-year securities, which were generally more liquid than other securities." The Federal Reserve did so to "support market functioning." They also state that "purchases of MBS were increased when market liquidity appeared to be good and were reduced when liquidity appeared to be poor." As far as I read these sentences, I have an impression that actual operations conducted by the Federal Reserve were not consistent with the philosophies of the LSAPs program; in fact, it is closer to conventional policy operations.

Of course, this does not rule out the possibility that some of the monetary operations during the crisis, especially operations conducted at the early stage of the crisis, were indeed carried out closely following the original philosophies of the LSAPs program. However, we should learn from the Federal Reserve's actual behavior in the market that distinction between conventional and unconventional monetary operations is not crystal clear as is often assumed in theoretical papers about unconventional monetary policy.

4. LSAPs and the Zero Lower Bound on Interest Rates

The authors state that LSAPs are "one of the key policy tools available at the zero bound" (Gagnon et al. 2011, p. 38). This is true, but the opposite may not necessarily hold. That is, LSAPs are available even when the policy rate is above zero. One may think that LSAPs are not desirable in an environment with positive interest rates, because LSAPs affect the level of interest rates, which is targeted by the central bank. However, LSAPs can be carried out with no effects on the level of the policy rate through appropriate sterilization.

An important question to be addressed is whether or not the use of LSAPs should be restricted only when the policy rate hits the zero lower bound. Cúrdia and Woodford (2010) and a series of papers by them adopt an assumption that central banks do not have skills to trade and monitor risky, illiquid assets. This assumption implies that LSAPs are costly, so that they should be used only when alternative policy tools (such as the control of the policy rate) are not available. This is consistent with what we observed in the United States, Japan, and other industrial countries.

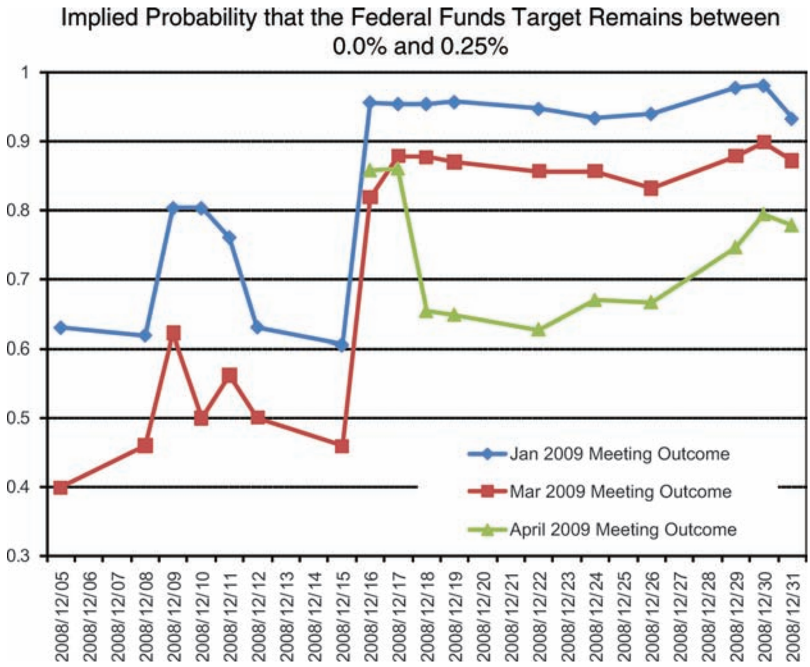
I do not see any problem with the Cúrdia-Woodford assumption. It is true that central banks do not have sophisticated skills to trade and monitor risky assets. However, the experience at the Federal Reserve Bank of New York tells us that the central bank is able to overcome the lack of such skills by borrowing skills from the private sector. Specifically, the authors state that the Federal Reserve Bank of New York hired external investment managers in order to quickly and efficiently implement the MBS purchases and to mitigate financial and operational risk. I'm not quite sure how much these managers contributed to the trading and monitoring activities at the Federal Reserve during the crisis, but this experience at the Federal Reserve seems to suggest that it might not be appropriate to rely too much on the Cúrdia-Woodford assumption.

The paper contains potentially important empirical evidence related to this issue. Their event-study analysis indicates that the impact of the LSAPs on the ten-year term premium is somewhere between 62 and 91 basis points, while the time-series analysis (using the data from the pre-crisis period) indicates that the corresponding figure is somewhere between 38 and 82 basis points. This difference implies that LSAPs were more effective in the crisis period during which financial markets did not work properly, although the authors did not conduct any statistical test for the difference in the estimated values. If this is the case, one may be able to argue that the use of LSAPs should be restricted only when financial markets do not function well.

5. The Effect of Policy Communications

The authors argue that the FOMC statements that the federal funds rate will remain at "exceptionally low levels for some time" (December 16, 2008) or "exceptionally low levels for an extended period" (March 18, 2009) did not change much the market expectation about the future path of the federal funds rate, based on the evidence that the one-year-ahead expected instantaneous interest rate did not move much around the release of the FOMC statements. Based on this argument, they conclude that the observed reductions in

Figure 1. Federal Funds Rate Predictions after December 16, 2008



Source: Federal Reserve Bank of Cleveland.

long-term interest rates, like the ten-year Treasury yield, come not from lower expectations of future short-term interest rates but from changes in term premiums.

To evaluate the (in)effectiveness of the policy commitment in a different way, I show some evidence in figure 1. This figure shows the implied probability that the federal funds target rate remains very low (i.e., between 0 and 0.25 basis points), which is estimated by the Federal Reserve Bank of Cleveland using prices of federal funds futures and options. The implied probability for the January 2009 meeting outcome (the probability that the federal funds target decided at the January 2009 meeting would be between 0 and 25 basis points) jumped up on December 16, 2008, when the FOMC lowered the federal funds target to a range of 0 to 25 basis points and stated that the federal funds rate was likely to remain at exceptionally low levels for some time. The same thing was true for the May 2009 meeting outcome. Turning to the April 2009 meeting outcome, however, the implied probability was high for two days after the FOMC statement but started to decline on December 18, 2009, and remained low thereafter. In other words, market participants expected on the day of the FOMC statement that the federal funds rate would remain at very low levels at least until April 2009, but that expectation lasted only for two days. They started to expect that low rates would end before April 2009. This is consistent with the evidence provided by the paper.

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On the Quantitative Effects of Unconventional Monetary Policies in Small Open Economies*

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This paper quantitatively evaluates the effects of several unconventional monetary policies for small open economies. In particular, a New Keynesian model is extended to include a liquidity premium, deviations from uncovered interest rate parity, and a premium in the term structure of interest rates, allowing the central bank to choose, in addition to its policy rate, the size and composition of its balance sheet. The model is calibrated to the case of Chile. We find that policies affecting the liquidity channel can potentially have large effects, but these depend on expectations about the future policy rate. On the other hand, alternatives working through the term premium have smaller effects, but they are less dependent on the expected path of the reference rate. We also study the possibility of undoing the unconventional policy as a possible exit strategy, with results indicating that this alternative may induce a significant slowdown, particularly if it is anticipated. Finally, we also consider the alternative of driving down the policy rate to its lower bound and maintaining it there for a prolonged period. While this policy can also be greatly expansionary, particularly after contractionary shocks, credibility issues regarding the promise of keeping the rate low for some time can severely undermine these effects.

JEL Codes: E4, E5.

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1. Introduction

In normal times, many central banks use the nominal interest rate as the policy instrument to achieve their inflation goals. However, when the policy rate reaches its lower bound, the monetary authority has to look for alternative (or unconventional) policies. What are the different tools that a central bank can use in such a situation? What are the quantitative effects of these policies? Although there is a significant branch of the literature that has evaluated the virtues of different options,[1] the analysis of the quantitative impact of different unconventional policies is much less frequent. Moreover, while until recently the experience of Japan (having a near-zero interest rate since the mid-1990s) was almost the only case of study, nowadays the aggressive response of many central banks aimed at dampening the effects of the 2008–09 crisis—taking the interest rate to its lower bound—further emphasizes the need for a quantitative assessment of different policy alternatives.

This paper is an attempt in this direction, presenting a quantitative exploration of different alternatives based on a dynamic and stochastic general equilibrium (DSGE) model, focusing on the small open-economy case.[2] In particular, we extend a simple New Keynesian model of a small open economy to include three frictions: a liquidity premium that introduces a gap between the policy rate and that of short-term debt, which depends on the velocity of base money; a portfolio-balance effect for the determination of the nominal exchange rate (implying deviations from the uncovered interest rate parity, UIP); and a premium in the term structure of interest rates that depends on the relative stock of short and long maturity of debt. These frictions, albeit introduced in an ad hoc fashion, allow the central bank to choose not only the interest rate as its policy tool but the composition of its balance sheet as well (the stock of money, short- and long-term debt, and foreign assets).

[1]See, for instance, Svensson (2001), Eggertsson and Woodford (2003), and Bernanke and Reinhart (2004), among many others.

[2]There are some quantitative studies in the literature for developed economies using DSGE models. An early example is Coenen and Wieland (2003), who analyze several alternatives for the case of Japan. More recently, Cúrdia and Woodford (2009), Gertler and Karadi (2009), and Eggertsson et al. (2010), among others, present studies for the recent experience in the United States.

We use this model to evaluate the dynamics generated by different changes in the central bank's balance sheet, taking into account the expected path for the policy rate, alternative "exit strategies," the possibility of (exogenous) lack of credibility in the policy announcements, and the role of the zero lower bound. The model is calibrated to the case of Chile, which is one of the countries that have driven the policy rate down to its lower bound during the 2008–09 crisis. In addition, from a methodological perspective, we present an algorithm, based on the idea of backward induction, to perform these types of exercises in the context of linear rational expectations models.

The results appear to indicate that policies working through the liquidity channel can potentially have important expansionary effects, which are generated not by the direct effect that a monetary expansion has in reducing this premium but rather through the expected future inflation that the increase in base money generates. However, these effects greatly depend on the perception about the future path of the interest rate and its credibility. On the other hand, policies aimed at reducing the term premium, while generating smaller expansions, are less dependent on the expected behavior of the policy rate and on credibility issues. The channel associated with the deviations from UIP seems to be of minor importance. We also consider the possibility of undoing the original change in the balance sheet as a possible exit strategy. This exercise shows that reversing the unconventional policy can generate important contractions, particularly if these changes are anticipated.

We also study the virtues of a temporary departure from the Taylor rule by which the central bank drops the policy rate down to the zero bound and keeps it there for an extended period of time. We find that this policy can be highly expansionary as well, and particularly useful after a contractionary shock that makes the zero limit binding endogenously. However, the issues regarding the credibility of the announcement are also relevant in this case.

In terms of the related literature, several reasons explain the lack of studies quantifying the effect of unconventional policies. First, it is difficult to estimate the impact of these policies directly from the data, for, at least until recently, the lower bound episodes were almost exceptional, limiting the power of direct econometric inference. The alternative is to use a model to tackle these issues, which is the route taken in this paper. However, this is not a trivial task either. On one hand, allowing for the interest rate to have a lower limit entails considering non-linearities in the model, which are generally difficult to handle computationally. On the other hand, even assuming that we can circumvent the computational issues, most models (particularly in the New Keynesian tradition) are not rich enough to allow for the monetary authority to use several different instruments. For instance, the role of money and liquidity is generally absent in these models, as well as the role of financial frictions.[3] In this work, we tackle the non-linearity by allowing the interest rate to be fixed at an arbitrary value (possibly zero) for some time as a way to capture deviations from the linear Taylor rule,[4] and we introduce frictions, although in an ad hoc way, in order to consider different policy tools.[5]

Before turning to the analysis, a caveat is in order concerning the type of policies analyzed and the kind of country analyzed in this paper. The term "unconventional policy" has been used somewhat vaguely, referring to a number of alternative tools that simply depart from the usual management of the monetary policy rate (e.g., in terms of a model, an unconventional policy could be any departure from the Taylor rule). One such alternative implemented during the recent crisis was the purchase by central banks of risky financial assets that were not part of the usual portfolio of these institutions, a type of policy that is generally labeled as credit policy. These alternatives were aimed at reducing a financial distortion that had widened due to the drop in the price of assets used as collateral (e.g., mortgage-backed securities). Moreover, it is likely that these central

[3]Some recent studies attempt to expand the basic framework along these lines—for instance, Cúrdia and Woodford (2009) and Gertler and Karadi (2009).

[4]Although we allow for non-linearities, we are still focusing on a local solution, as most studies in this topic do. A different branch of the literature characterizes global solutions, showing that important differences may arise—most remarkably, the possibility of converging to a liquidity trap (see, for instance, Benhabib, Schmitt-Grohe, and Uribe 2001, 2002). This alternative, however, is not explored in this paper.

[5]The fact that frictions are not micro-founded is clearly a drawback of the analysis. However, given that the literature has not yet arrived at a consensus on which are the relevant frictions or how to model them, this analysis can provide some insight on which are the relevant parts of the model (or "wedges") that should be the focus of this research agenda.

banks would have implemented this same type of strategy regardless of the policy rate reaching its lower bound.

Although these alternatives are relevant to discuss as well, we do not analyze them in this paper for several reasons. First, these are not the only types of policies that have been evaluated and/or implemented, for many countries did not have to deal with a situation of deep financial distress. For instance, Céspedes, Chang, and García-Cicco (2011) compile a list of fifty-six policy announcements regarding unconventional policies, in the period from September 2008 to October 2009, for a group of thirteen central banks that generally implement (explicit or implicitly) inflation targets, finding that only twelve of these announcements were related to assets purchase programs or direct lending to (non-banks) financial firms, which were implemented by four central banks (Canada, Switzerland, England, and the United States). Moreover, this distinction seems particularly relevant for emerging countries. For instance, Ishi, Stone, and Yahoue (2009) document that for thirty-four emerging countries, most of the unconventional policies pursued between September 2008 and May 2009 were related to exchange rate interventions and to providing liquidity domestically, while only 3 out of 205 measures implemented according to their classification were related to credit-easing policies. This paper is then more representative of the situation faced by countries like Chile, Sweden, and Australia, among others, that drove the policy rate to its lower limit and had to look for other alternatives to stimulate the economy.

The rest of the paper is organized as follows. Section 2 presents the frictions introduced as well as the alternative policy tools that the central bank has available. We also show there the estimation exercise using Chilean data. In section 3 we present the quantitative results, where we analyze the role of different expected paths for the policy rate, lack of credibility, possible exit strategies, the role of the zero bound, and the response to contractionary shocks, as well some robustness exercises. Finally, section 4 concludes.

2. Model and Calibration

The structure of the model corresponds to a standard New Keynesian framework for a small open economy with incomplete asset markets, modified to introduce ad hoc frictions (or wedges in the usual equilibrium conditions), allowing the central bank (CB) to decide over the different elements in its balance sheet, in addition to its policy rate. In particular, we consider a structure with households having separable preferences in consumption and leisure and that can transfer resources over time using an internationally traded bond, money, and bonds of different maturities issued by the CB. They consume a combination of domestic and foreign goods. There is also an infinite number of monopolistic intermediate goods firms that use labor to produce, with a constant returns to scale technology, and that are subject to a Calvo-type problem in setting prices, with full indexation to past inflation. Finally, with the goal of simplifying the analysis, we abstract from capital as a productive input (and therefore investment), as well as from fiscal policy.

In this section we first describe the optimality conditions associated with households' assets decisions in the standard model and then describe the modifications we introduce.[6] Then, we characterize the CB and the several policy alternatives we consider. Finally, we discuss the estimation of the parameters describing the frictions we introduce. Appendix 1 contains a description of the other equilibrium conditions of the model. Appendix 2 contains the figures referred to in the paper.

2.1 Assets and Monetary Policy in the Standard Model

We begin by describing the budget constraint and the optimality conditions in the frictionless model to see how they reduce the CB policy alternatives to only one instrument (generally, the interest rate associated with short-term bonds). Consider the following budget constraint faced by households:

$$P_tC_t + \frac{S_tB_t^*}{1+i_t^*+cp_t} + \frac{D_{1,t}}{1+i_{1,t}} + \frac{D_{2,t}}{1+i_{2,t}} + \frac{M_t}{1+i_t^M} \leq W_tL_t + S_tB_{t-1}^* + D_{1,t-1} + \frac{D_{2,t-1}}{1+i_{1,t}} + M_{t-1} + T_t.$$

[6]As we mentioned in the introduction, these modifications are introduced ad hoc, with no microfoundations. Nevertheless, we discuss alternative mechanisms (introduced in the related literature) that may produce such departures from the standard model.

Here, C_t denotes consumption, S_t is the nominal exchange rate, P_t is the price level, W_t stands for nominal wages, L_t is hours worked, and T_t is lump-sum transfers from the CB. In terms of assets, households have access to an internationally traded bond B_t^* that has a price given $1/(1 + i_t^* + cp_t)$ (where i_t^* is the world interest rate and cp_t is the country premium that "closes" this small open-economy model), bonds issued by the CB ($D_{k,t}$ is a bond of maturity k with rate $i_{k,t}$),[7] and money, M_t, which has an acquisition price equal to $1/(1 + i_t^M)$ (we discuss the role of this rate below).

In the frictionless model, the first-order conditions associated with asset decisions can be written, after a log-linear approximation, as[8]

$$\hat{\lambda}_t = E_t\{\hat{\lambda}_{t+1}\} + i_{1,t} - E_t\{\hat{\pi}_{t+1}\}, \tag{1}$$

$$i_{2,t} = i_{1,t} + E_t\{i_{1,t+1}\}, \tag{2}$$

$$i_{1,t} = i_t^* + cp_t + E_t\{\hat{s}_{t+1}\} - \hat{s}_t, \tag{3}$$

$$i_{1,t} - i_t^M = -\varphi_m(\hat{m}_t - \hat{p}_t - \hat{y}_t), \tag{4}$$

where λ_t is the marginal utility of consumption and the parameter φ_m will depend on the specific assumption about the role of money.[9]

In the usual treatment of this model, it is also assumed that $i_t^M = 0$ and that the policy rate, i_t^{MP}, equals the short-term rate $i_{1,t}$. Therefore, in the standard model there is only one monetary policy instrument available (usually i_t^{MP}, which is determined by a Taylor-type rule) and the different elements in the CB balance sheet are irrelevant for the determination of other asset prices: the demand

[7] We only consider two-period bonds here to ease the notation, while in the estimation we allow for maturities in line with those available in our empirical case, Chile.

[8] We use small-caps hatted variables to denote log-deviations from the steady state.

[9] Here we are implicitly assuming that, in the absence of price stickiness, money is neutral, as it is generally assumed by the "cashless limit" modeling strategy. Additionally, it is worth mentioning that in a fully micro-founded model (particularly in one of a small open economy) consumption should appear in equation (4) instead of output. However, because in our estimation we use monthly data to overcome a short available sample, we use output because we do not have available a monthly consumption series, but we do have a monthly series for aggregate economic activity. Finally, we are implicitly assuming that money demand has a unitary elasticity with respect to output.

for real balances (4) determines the stock of money for a given i_t^{MP}, the expectations hypothesis (2) determines interest rates at different horizons, and equation (3) (the uncovered interest parity, UIP) pins down the exchange rate. To overcome this impossibility, in what follows we redefine the monetary policy rate and introduce wedges in these familiar conditions, in such a way that the stock of different assets will show up in equilibrium.

2.2 Modifying the Standard Framework

The first departure from the standard framework is to modify the assumption $i_t^M = 0$ and to consider this to be the policy rate (i.e., $i_t^{MP} = i_t^M$). The motivation behind this choice is that usually the target for the policy rate is not that of a short-term bond but, instead, that of a monetary market, such as the overnight or the repo rate. These are the types of markets that CBs actually use to introduce money into the economy through open-market operations and, although in those markets Treasuries and/or CB bonds are generally exchanged for money, the interest rates charged for these operations do not need to (and generally they actually do not) coincide with that of these assets, for the latter may generally include a liquidity premium.[10]

We are not the first, however, to use this type of assumption. For instance, Reynard and Schabert (2009) introduce a framework explicitly modeling the market for money where only short-term bonds are eligible for money acquisitions. In their framework monetary policy targets the rate prevailing in that market, which is generally different from that of other assets in the economy. Sims (2009) also considers a model with two policy rates, although his interpretation for the rate i_t^M is rather different, for he considers this to be the interest rate paid on reserves as a way to capture the policy recently implemented in the United States by the Federal Reserve.

This assumption introduces an additional degree of freedom for monetary policy, which can now be implemented by choosing two instruments—in our case, i_t^M and the stock of money M_t—leaving

[10]Such a premium does not need to be high (as it doesn't seem to be in the data) for this mechanism to work, but as long as it exists, this mechanism will generate the results presented below.

the short-term rate $i_{1,t}$ to be determined by equation (4). From a technical point of view, this assumption has also been considered in some textbook treatments such as Woodford (2003, chap. 2). In particular, Woodford shows (in the context of a flexible-price model) that a monetary policy specified by exogenous paths for both i_t^M and M_t will deliver a determinate equilibrium.[11] This result is relevant because, although we will consider a familiar Taylor-type rule for i_t^M satisfying the Taylor principle as the "normal times" policy rule (see below), we can also assume that i_t^M is fixed at a given value forever without facing indeterminacy issues, a feature that we will exploit to consider unconventional monetary policies.

From a qualitative point of view, given this friction, a permanent increase in the stock of M_t will have, ceteris paribus, two effects. On one hand, the reduction of $i_{1,t}$ will increase desired consumption. On the other hand, the rise in M_t will increase the price level which, in the presence of price rigidities, will generate expectations of future inflation, reducing the real interest rate and further expanding consumption demand.

The second difference with the standard framework is that we also consider deviations from the uncovered interest rate parity (UIP) such that

$$\hat{s}_t - E_t\{\hat{s}_{t+1}\} - i_t^* - cp_t + i_{1,t} = \varphi_s\big(\Delta \hat{b}_t^{*BC}\big), \tag{5}$$

where Δ denotes the first-difference operator and B_t^{*BC} denotes the holdings of foreign assets by the CB (described below). In this way, changes in the CB holdings of foreign assets will have a direct effect (ceteris paribus) on the nominal exchange rate.[12]

Finally, we modify equations (1) and (2) to consider a term premium in the yield-curve structure that affects intertemporal allocations. In particular,

$$\hat{\lambda}_t = E_t\{\hat{\lambda}_{t+1}\} + i_{1,t} - E_t\{\hat{\pi}_{t+1}\} + \Delta \hat{tp}_t, \tag{6}$$

[11] See proposition 2.11. This result is also present in the model of Reynard and Schabert (2009), which additionally features price rigidities.

[12] A similar deviation from the UIP gap can be obtained in a model with costly adjustment of the international portfolio. See, for instance, Sierra (2008).

where

$$\hat{tp}_t \equiv i_{2,t} - i_{1,t} - E_t\{i_{1,t+1}\} = \varphi_k(\hat{d}_{2,t} - \hat{d}_{1,t}). \tag{7}$$

Therefore, different combinations of long- and short-term debt will have first-order effects in consumption decisions.[13] In particular, either increases in $D_{1,t}$ or drops in $D_{2,t}$ will shift consumption demand upward.[14]

2.3 Monetary Policy

In each period t, the CB decides on four types of assets: base money (M_t), foreign reserves (B_t^{*CB}), and domestic debt of both short and long maturity ($D_{1,t}^{CB}$ and $D_{2,t}^{CB}$).[15] Additionally, it chooses the monetary policy rate i_t^{MP} and lump-sum transfers to households (T_t).

The CB resource constraint in any given period is given by[16]

$$\frac{S_t B_t^{CB*}}{1 + i_t^* + cp_t} + D_{1,t-1}^{CB} + \frac{D_{2,t-1}^{CB}}{1 + i_{1,t}} + M_{t-1} = S_t B_{t-1}^{CB*} + \frac{D_{1,t}^{CB}}{1 + i_{1,t}} + \frac{D_{2,t}^{CB}}{1 + i_{2,t}} + \frac{M_t}{1 + i_t^M} + T_t.$$

[13]In principle, we could consider the possibility of $\Delta\hat{tp}_t$ entering the Euler equation with a coefficient different than one. However, to estimate such a coefficient will be difficult, for there is no monthly data on consumption. Nevertheless, in the robustness section we check the robustness with respect to the parameter φ_k, which can be seen also as a robustness check in terms of modifying this assumption.

[14]A similar modification of the Euler equation and the expectation hypothesis can be obtained, for instance, in line with Andres, López-Salido, and Nelson (2004), by assuming imperfect assets substitution between long- and short-term bonds.

[15]That a CB can issue its own debt is not a commonly observed characteristic, but it is the case for Chile. More generally, thinking of a CB that does not share this characteristic, we can interpret $D_{1,t}^{CB}$ and $D_{k,t}^{CB}$ as the negative of the CB holdings of Treasury bonds.

[16]In the absence of the frictions previously introduced, this equation is irrelevant in equilibrium.

It is further assumed that the CB uses transfers in such a way to rebate any capital gain/loss to households,[17] implying that the bank's total net worth is kept constant in nominal terms, i.e.,

$$\left(S_t B_t^{*CB} - S_{t-1} B_{t-1}^{*CB}\right) = (M_t - M_{t-1}) + \left(D_{1,t}^{CB} - D_{1,t-1}^{CB}\right) + \left(D_{2,t}^{CB} - D_{2,t-1}^{CB}\right). \quad (8)$$

In normal times, policy is conducted through a familiar Taylor rule,

$$i_t^{MP} = \rho_i i_{t-1}^{MP} + (1 - \rho_i)(\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t). \quad (9)$$

On the other hand, the unconventional policies that we will consider have two components: first, the policy rate is fixed at some value (either its steady-state level or zero) for some time and, second, the CB changes the position of an asset in its balance sheet, compensated by a change in another asset such that the bank's total net worth is kept constant in nominal terms (i.e., equation (8) holds).

2.4 Estimating the Frictions

Given the frictions previously introduced, different changes in the CB balance sheet may have different expansionary effects. To quantify these effects we need to assign values to the parameter describing these frictions (φ_m, φ_s, and φ_m), which we will obtain by estimating equations (4) to (7) using monthly Chilean data from January 2003 to May 2009.[18] Before presenting the results, it is relevant to mention several data limitations. First, even though there is data available on the total stock of bonds of the Central Bank of Chile (CBCh) on circulation, the data is not rich enough to obtain a long series for the stock of bonds at different maturities. In addition, although nowadays the CBCh has available a rich maturity structure for its

[17] Reynard and Schabert (2009), in a closed-economy model, make a similar assumption. In principle, this is not the only possibility one can consider. But allowing for a change in the CB net worth would require setting a rule for the evolution of this variable, and it is not clear how this rule should be specified (nor is there guidance in the literature on these issues). This exercise, on the other hand, is simpler and will allow us to obtain a cleaner intuition.

[18] The calibration of the other parameters in the model follows the related literature and is described in appendix 1.

bonds, this has not been always the case, and only the two-year bond in pesos (BCP2) has a long enough series of interest rates.

In terms of equation (4), i_t^{MP} is measured by the monetary policy rate set by the CBCh, $i_{1,t}$ is the ninety-day deposit rate,[19] M_t is the monetary base, output is the monthly index of economic activity (IMACEC), and the price level is the core consumer price index (IPCX1).[20] The equation was estimated by GMM, using as instruments five lags of the regressors, the JP Morgan Emerging Markets Bond Index Global (EMBI Global), the federal funds rate, the rate on a five-year bond in pesos (BCP5), and the ninety-day lending rate, and allowing also for an AR(1) error term.[21] The result obtained was[22]

$$\begin{aligned} i_{1,t} - i_t^{MP} &= \underset{(0.0017)}{-0.0025} - \underset{(0.0007)}{0.0014}(\hat{m}_t - \hat{p}_t - \hat{y}_t) + u_t, \\ u_t &= \underset{(0.0416)}{0.8056}\, u_{t-1} + e_t, \\ R^2(Adj) &= 0.587, J - stat = 0.175, Obs = 60. \end{aligned}$$

For equation (5), the foreign interest rate is the federal funds rate, and the country premium is measured by the EMBI, the stock of government foreign assets B_t^{*CB} was measured by the net foreign asset element in the CBCh balance sheet, and the three-month-ahead expectation of the nominal exchange rate comes from the Expectations Survey collected by the CBCh. The equation was estimated by GMM using the same instruments as in the previous equations and allowing also for an AR(1) error term. The results were

$$\begin{aligned} \hat{s}_t - E_t\{\hat{s}_{t+1}\} - i_t^* - cp_t + i_{1,t} &= \underset{(0.001)}{-0.0037} + \underset{(0.036)}{0.2047}\left(\Delta \hat{b}_t^{*BC}\right) + u_t, \\ u_t &= \underset{(0.0307)}{0.2615} u_{t-1} + e_t, \\ R^2(Adj) &= 0.014, J - stat = 0.115, Obs = 76. \end{aligned}$$

[19] All rates are quarterly to be consistent with the calibration of the model.

[20] These two series have been seasonally adjusted. The source for all the series is the Central Bank of Chile. Variables are measured in logs.

[21] Adding lags of the dependent variable as regressors did not improve the goodness of fit.

[22] Newey-West robust standard errors are in parentheses.

Several studies have used this type of deviation from UIP for their analysis, and it is useful to compare their calibration with the results obtained here.[23] For instance, in an application for Japan, Orphanides and Wieland (2000) and Coenen and Wieland (2003) calibrate a parameter that governs the relation between deviation from UIP with respect to the level of foreign reserves to 0.025. On the other hand, in an empirical study for the United States and Germany by Baillie and Osterberg (2000), they find an elasticity with respect to deviations from UIP to foreign exchange interventions between 0.01 and 0.02. While these numbers are significantly smaller than what we obtained for the case of Chile, we should remember that these alternative figures come from studies of developed countries, and it is therefore reasonable to believe that this elasticity should be bigger for an emerging country.

Finally, for equation (7) the rate of nominal two-year bonds was used as a measure for $i_{k,t}$, and the expectations about the future short rate also come from the Expectations Survey. Because, as we commented before, there is no data on the stock of bonds at different maturities, we measure $\hat{d}^{BC}_{k,t} - \hat{d}^{BC}_{1,t}$ as the difference between the total stock of bonds in pesos and the stock of ninety-day commercial and consumer deposits. The equation was estimated by GMM using the same instruments as in the previous equations and allowing also for an AR(1) error term. The estimation yields

$$i_{k,t} - \sum_{j=0}^{k-1} E_t\{i_{1,t+j}\} = \underset{(0.001)}{-0.001} + \underset{(0.001)}{0.017}\left(\hat{d}^{BC}_{k,t} - \hat{d}^{BC}_{1,t}\right)u_t,$$

$$u_t = \underset{(0.0307)}{0.2615}\, u_{t-1} + e_t,$$

$$R^2(Adj) = 0.671, J - stat = 0.179, Obs = 76.$$

We can also compare this result with some papers that try to assess the effect of the composition of the Treasury holdings by the Federal Reserve. For instance, Bernanke, Reinhart, and Sack (2004) analyze

[23] There is a larger literature that addresses the effect of foreign exchange interventions on the exchange rate. This is, however, different from the parameter that we need to calibrate because we need the influence of changes in the CB foreign reserves on deviations from UIP.

the effect of two refunding episodes, finding an effect of 10 basis points in the Treasuries spread between five and two years of maturity. More recently, Gagnon et al. (2011) uses a time-series approach to measure the elasticity of the ten-year Treasury rate to changes in the supply of long-term Treasuries, finding that a 1-percent-of-GDP increase in long-term debt produces a drop in this rate between 4 and 10 basis points. While the elasticities computed in these exercises are not exactly the same as those we measured here, the results seem to be in line with these related studies.

Finally, it is relevant to highlight that these equations are not meant to represent a full theory explaining these gaps observed in the data (e.g., not all deviations from UIP are due to exchange rate interventions). Actually, the share of the variance of the left-hand-side variables explained by the proposed regressors is generally low. Nevertheless, the fact that the coefficients display the correct sign and appear to be statistically different from zero suggests that some explanatory power can be attributed to the proposed regressors.

3. The Effect of Unconventional Policies

We proceed with the numerical exercises in several steps. First, we study the effects of a given change in the CB balance sheet assuming that i_t^{MP} remains fixed in its steady-state value forever. Although this is clearly not a realistic assumption, it will be useful to grasp the intuition behind the dynamics implied by the different alternatives. Second, we analyze what happens if the CB promises to keep i_t^{MP} fixed at its steady-state value only for a limited amount of time, using the Taylor rule afterward. Additionally, we allow people to assign an exogenous probability to the event that the CB returns to the Taylor rule before it was promised. Third, the possibility of undoing the unconventional policy (either by a surprise or with an anticipated announcement) as a possible exit strategy is considered. Fourth, we evaluate the virtues of driving the policy rate down to zero and maintaining it there for some time as an additional unconventional policy alternative. Fifth, we hit the economy with a contractionary shock and study how these policies can be used to ameliorate the recession. Finally, we check the robustness of the results to several perturbations to the model.

3.1 Fixing i_t^{MP} Forever

The exercise we consider first is to fix i_t^{MP} at its steady-state value forever and to permanently change two components of the CB balance sheet in such a way that equation (8) is satisfied. In particular, we assume that the change in the balance sheet is equivalent to 10 percent of nominal GDP in steady state.

Figure 1 shows the effect of a purchase of foreign assets financed with an increase in the stock of money. (All figures referred to in this paper can be found in appendix 2.) This policy generates an increase of 6.1 percent in inflation and a rise in GDP of 3.7 percent on impact, and these positive effects last for several quarters. The fact that the response of inflation lies always above zero indicates, in line with the discussion before, that the price level experiences a permanent change in the long run.[24] This change does not fully materialize in the first quarter due to the price rigidities, generating, in particular, an increase in expected inflation. This rise in expectations reduces the ex ante real interest rate, $r_t \equiv i_{1,t} - E_t\pi_{t+1}$, which has an expansionary effect. In principle, this rate is also reduced by the drop in $i_{1,t}$. However, as can be seen in the figure, $i_{1,t}$ decreases by little compared with the increase in $E_t\pi_{t+1}$.

This alternative also has an effect through the exchange rate channel in equation (5). To see how important this mechanism is, the dashed-dotted line in figure 1 displays the same response assuming $\varphi_s = 0$. As can be seen, the responses are quite similar compared to the benchmark case, which further emphasizes the role of the increase in expected inflation as the relevant channel.

Monetary expansions can also be used to purchase either type of CB debt. In this case, the channel in equation (5) will play no role, but we may have an additional expansionary effect if long debt is acquired, for it reduces the term premium in equation (7). Figure 2 displays the dynamics under both alternatives. We can observe effects on impact on GDP and inflation similar to the previous exercise, with a slightly bigger effect in the case of a purchase of $D_{k,t}^{CB}$.

[24] Actually, given that equation (4) depends on velocity, and given that the stock of money increases by 10 percent of GDP, the integral of the response of inflation should be 10 percent, which can be verified numerically.

There is a somewhat smaller response on the real exchange rate in this case (the impact response in the previous case was a real depreciation of near 5.3 percent, while in this case it is around 4.7 percent), but in general the dynamics are similar, indicating that this alternative also creates an expansionary effect through the rise of inflation expectations.

In terms of policies that do not involve monetary expansions, figure 3 plots the responses to a purchase of long debt financed by new short debt, a policy that has a direct effect through the term premium channel in equation (7). This alternative generates a milder expansion of GDP and inflation on impact, 0.3 percent and 0.05 percent, respectively. While the nominal exchange rate depreciates in this case, there is a real appreciation on impact, which partially explains this smaller response. Moreover, given the shape of the inflation path, the real interest rate actually rises and therefore the expectations channel is not present in this case.

Finally, figure 4 shows the effect of a purchase of foreign assets financed with either long or short new debt. In this case, both the friction affecting the UIP condition, equation (5), and the yield curve, equation (7), are in place. However, we can see that the effect on output is only positive when the operation involves an increase in $D_{1,t}^{CB}$, which appears to indicate that the second channel is relatively more important. Additionally, while the increase in output is smaller compared with the case in figure 3, the response of inflation (at least on impact) brought about by the nominal depreciation is bigger in this case, although this change is reversed in the second quarter.

Overall, these exercises highlight that policies working through the liquidity channel may have significant effects, while other alternatives can also have expansionary effects but of a smaller magnitude. However, the maintained assumption so far was that the monetary policy rate is expected to remain fixed forever. In what follows, we relax this important assumption.

3.2 A Temporary Fix of i_t^{MP}

We consider the following exercise. At time t_0, the CB announces that the policy rate is going to stay fixed until period $T-1$, and from

T onward it will be determined according to the Taylor rule in equation (9). Additionally, it announces an unconventional policy, which also takes place at t_0 but that will never be reversed (an alternative that we consider in the next subsection). Everybody believes that, beginning at period T, the Taylor rule will be in place and that it will stay for any $t \geq T$. However, for $t \in [t_0, T-2]$, while the interest rate is fixed, people assign an exogenous probability sequence p_t to the CB breaking its promise and setting the nominal interest rate according to the Taylor rule starting at $t+1$. Moreover, if this is the case, they believe that the Taylor rule will stay forever. Finally, regardless of people not trusting the CB, we assume that (ex post) it fulfills its promises and actually waits until T to use the Taylor rule. Appendix 1 presents an algorithm, based on the idea of backward induction applied to linear rational expectations models, that can be used to compute the equilibrium trajectories under these assumptions. The algorithm also constrains the equilibrium path to satisfy the non-negativity constraint on the policy rate.

We begin with the case of a purchase of foreign assets financed by a monetary expansion. Figure 5 shows the dynamics for different T's, assuming full credibility (i.e., $p_t = 0$). As can be seen, allowing the Taylor rule to return after some time significantly dampens the expansionary effects of this alternative. For instance, if the policy rate is fixed for eight quarters, the impact response of output is near 0.9 percent, dropping to close to 0.2 percent for $T = 2$, while these figures for inflation are, respectively, close to 2 percent and 0.7 percent. These are significantly smaller than the rise of 3.7 percent in GDP and 6.1 percent in inflation that is generated if i_t^{MP} stays fixed ad infinitum.

In part, this smaller effect is due to the qualitatively different response of inflation: while before it used to lie completely above zero, now it increases on impact, decreases to a negative value in the second quarter, and then becomes positive and converges to zero from above.[25] This different path for inflation translates into a

[25]The cumulative response of inflation (i.e., the price level) is the same in the long run in both cases (equal to 10 percent as we dicussed before). However, while in the case of i_t^{MP} fixed forever the convergence was after just a few periods, it now takes more than 3,000 quarters to reach this value.

less expansionary path for the real interest rate, which now actually increases on impact and then becomes negative, converging to zero from below. Although the infinite sum of the real interest rate (i.e., the relevant measure for the determination of consumption according to the IS curve) is still negative (close to –0.6 percent when $T = 8$), it is significantly smaller than before (almost –4 percent), which explains why the response of output has dampened in this case.

However, this is only a part of the explanation, for the shape of the inflation path changes in this case because inflation is more affected by the dynamics of the nominal exchange rate than before, which explains why it decreases below zero in the second quarter.[26] In particular, if $\varphi_s = 0$, the response of inflation lies completely above zero. However, it is still the case that the convergence of the price level to its new steady state is much slower.

The difference in terms of the speed of convergence of the price level is clearly due to the expected rise in the policy rate. In particular, although this increase is small (less than 3 basis points when $T = 2$), the path of the interest rate also lies above zero for a significant period of time (until the price level converges to its new steady-state value).[27] Of course, this description cannot be interpreted causally, for both inflation and interest rates are jointly determined in equilibrium. However, it is clear that the anticipation of the return to the Taylor rule significantly limits the expansionary effect that this policy alternative may have.

We consider next the effect of lack of credibility. Figure 6 shows the same unconventional policy, fixing $T = 6$, and setting $p_t = p^t$ for different values of p (this implies that, as times goes by and people see that the CB has actually kept its promise, the assigned probability of an anticipated return to the Taylor rule decreases). This lack of credibility also dampens the expansionary effect that this policy

[26] Actually, as can be seen in figure 1, the response of inflation also displayed a small negative bump in the second quarter even with the policy rate fixed forever. However, the response of inflation in that case was so large that this had a minor impact.

[27] Taken together, while the infinite sum of the real interest rate is more negative if $\varphi_s = 0$ (close to –1.2 percent when $T = 8$), it is still significantly smaller than what it was in the case of the policy rate fixed forever.

may have. In particular, for $p = 0$ the impact increase in GDP is close to 0.5 percent, but with $p = 0.9$ it drops to almost 0.3 percent. The response of inflation is also milder the higher this probability is, although the difference is relatively smaller. Overall, the patterns are similar to those described for the case of $p_t = 0$.[28]

We can also consider how the results are affected if the unconventional policy implemented is a purchase of long-term debt financed with new short-term debt. Figure 7 shows the dynamics for different T's, keeping $p_t = 0$. Compared with the case of a monetary expansion, here the responses of output and inflation are not that sensitive to changes in T. Actually, the effects seem to be slightly bigger than the case of i_t^{MP} fixed forever, and the responses of both variables now lie completely above zero. This different shape particularly generates a drop in real interest rate, and although the policy rate rises once the Taylor rule returns, the increase is quite small and the real rate remains below zero for several periods.[29] Finally, we analyze the effect of this policy when people assign a positive but decreasing probability to the early return of the Taylor rule, a case described in figure 8. It appears that the dynamics are not significantly affected either when we allow for p_t to vary.

3.3 Undoing the Unconventional Policy

Part of the current discussion about unconventional policies refers to possible "exit strategies," which is clearly a broad term. In principle, one can consider a return to the usual Taylor rule being, in itself, an exit strategy. However, the discussion appears to focus on undoing the unconventional policy initially implemented. For instance, one might be worried about the effects that the excess of liquidity introduced. As an example, we described before how a policy that entails increases in M can generate significant persistence in the inflation

[28]Other policies that entail an increase in M also show results similar to those obtained in this case.

[29]This actually suggests that, for this type of policy, the responses vary non-monotonically with changes in T. In the case of a monetary expansion, the bigger the T, the bigger and closer to the case of i_t^{MP} fixed forever the responses were. In this case, on the contrary, there seems to be a value for T (in the numerical exercises it is close to 25) such that the responses are bigger at that point, becoming closer to the case in figure 3 afterward.

process once the Taylor rule is reintroduced. In what follows, we present several exercises that help to sharpen this discussion.[30]

A first alternative is to consider the same policies as before (i.e., the CB announces an unconventional policy and that i_t^{MP} will be fixed until $T-1$, and the Taylor rule will be used for $t > T$) and to additionally assume that the CB also announces that in period $T-k$ (with $k \in [0, T-t_0+1]$) the unconventional policy will be completely reversed (assuming, for the moment, full credibility).[31] For instance, if at t_0 the CB buys foreign assets using base money, at $T-k$ it sells the same amount of dollars in exchange for currency. This alternative is considered in figure 9, which displays the equilibrium paths for different values of k. To clarify the exercise, the figure also displays the paths for M_t and B_t^{*BC}. It is clear that the anticipation of the reversal further dampens the expansion, actually generating a recession in most cases. In particular, the smaller the value of k, the more negative the responses of output and inflation are. This is because the policy reversal is contractionary and the effect is partially mitigated if the nominal rate remains fixed for more time.

These responses can be rationalized by realizing that the mechanism generating the expansion with a policy that expands M (i.e., the expected rise in the price level) disappears when the reversal is anticipated. Figure 10 actually shows that gradually undoing the unconventional policy is even worse when the change is anticipated, while figure 11 illustrates that if people believe that the change can occur earlier, the economy contracts even further.

We also explore the possibility of undoing the unconventional policy unexpectedly. Figure 12 displays the dynamics for different values of k, for the case of full reversal at $T-k$. Evidently, the impact response is the same we described in the previous subsection, and when the policy is undone we have a contraction, with output dropping slightly below zero at that time and inflation also becoming negative. What actually mitigates the negative effect on output is the fact that the shock is unanticipated: although inflation

[30]To simplify the exposition, we will just show the case of a purchase of foreign currency financed by a monetary expansion. The other alternatives yield qualitatively similar results.

[31]As shown in appendix 1, the algorithm can be generalized to consider this alternative.

drops on impact at $T - k$, it is expected to be positive in the next period (partly due to the dynamics of the nominal exchange rate), making the real interest rate negative and generating an increase in consumption demand. However, it is relevant to highlight that when the Taylor rule returns, the policy rate displays a minor drop (of less than a basis point) because both output and inflation converge to zero from below slowly. Finally, the case of a gradual reversal starting at $T - k$ is considered in figure 13. This reversal produces a bigger drop in output and inflation. However, inflation now converges from above zero and, consistently, the policy rate rises after period T.

3.4 Driving i_t^{MP} to the Lower Bound

So far we have kept the policy rate fixed at its steady-state level for some time as a way to complement the effects of changes in the CB balance sheet. However, we can alternatively consider the possibility of the CB driving the policy rate all the way down to its lower bound, which is also in line with the recent experience. For instance, Céspedes, Chang, and García-Cicco (2011) document that in a group of twenty countries with (implicit or explicit) inflation targets, thirteen of them drove the policy rate down to a lower bound at some point after September 2008 and have maintained it there for an extended period of time. Additionally, while maintaining the rate at its lower bound can be seen as a complementary action to enhance the effects of movements in the balance sheet, driving the policy rate to zero and leaving it there for some time also implies a departure from the usual Taylor rule. Therefore, we can consider this action an unconventional policy in itself, regardless of its potential role in complementing movements in the balance sheet.

Figure 14 shows the responses associated with a decrease (from its steady-state value) of the policy rate down to zero, leaving it at that value for alternative horizons, and assuming that afterward this rate is determined by the Taylor rule.[32] As can be seen, this policy alternative has important expansionary effects: for instance, if the rate drops to zero and remains at this value for one quarter,

[32]Notice that because the figure plots log-deviations from steady state, the lower bound in the graph corresponds to a value close to −1.6 percent (given that the steady state of this rate is, in annual terms, 6.5 percent).

output increases by nearly 5 percent while inflation rises by almost 7 percent. In addition, we can see that the key channel for this effect is the reduction in the ex ante real interest rate. To put these numbers in context, in order to obtain a similar response (on impact) for both inflation and output with an expansionary monetary shock to the Taylor rule, we would require a disturbance generating a drop on impact in the policy rate to −17 percent (in annual terms).

We can also analyze as before the role of (exogenous) credibility in the announcement of the policy rate staying at zero for some time. Figure 15 displays the response for the case in which it is announced that the Taylor rule will return after six quarters, but with people assigning a probability $p_t = p^t$ to the anticipated return of the Taylor rule in $t + 1$. In line with the results obtained previously, the effects of lack of credibility can be pervasive in this case as well, significantly dampening the expansionary effects brought about by the zero bound.

3.5 Contractionary Shocks and the Lower Bound

The analysis up to this point has focused on studying the alternative policies in isolation, a strategy followed to better understand the mechanics behind each of the alternatives. Nevertheless, probably the most interesting case is to study how these policies can be used after the economy is hit by a recessionary shock. In addition, this case will allow us to distinguish the role played by the zero bound when it is attained endogenously or exogenously. The first alternative refers to the situation in which a negative shock is big enough that it makes the policy rate indicated by the Taylor rule negative. In this case, the rate will remain at zero until the effect of the shock vanishes enough so that the Taylor rule prescribes to rise the rate. The second alternative, on the other hand, considers the possibility that the CB chooses to temporarily depart from the rule and keep the interest rate at zero even after the time in which the Taylor rule would have indicated to raise the policy rate.[33]

[33] In addition, it is also important to highlight that, because the equilibrium we compute is non-linear due to the presence of the zero bound, the response to a negative shock that drops the policy rate to zero is not the same as adding to the figures in the previous subsection the response that would have been obtained with this shock but without considering the lower bound.

The disturbance we consider is a preference shock that temporarily lowers the real interest rate in the flexible-price equilibrium, in line with Eggertsson and Woodford (2003) and much of the following literature.[34] In particular, the log-linearized Euler equation (6) now includes a variable $\hat{v}_t$ that follows an autoregressive process with a coefficient in its first and only lag of 0.7, which is in line with the estimates of Medina and Soto (2007) for Chile. In order to calibrate the size of the shock, we use a result from the empirical investigation of Céspedes, Chang, and García-Cicco (2011). They computed (for a group of CBs that decreased the policy rate to its lower bound during the 2008–09 period) the path of the interest rate that would have been implied by a Taylor rule if the interest rate was allowed to go below zero. In particular, for the small open economies in their sample—Canada, Chile, Sweden, and Switzerland—the average maximum difference (across countries and across several specifications for the Taylor rule) between their respective lower bound and the rate implied by the rule was 450 basis points (around 110 basis points at quarterly frequency). Therefore, we choose the value of the shock so that, in the alternative in which the policy rate is allowed to go below zero, the minimum value of the reference rate after the shock is around −1.1 percent at a quarterly frequency.[35]

As a first step, figure 16 displays the responses to the shock under two specifications for the Taylor rule, without including any

[34] In terms of the recent episodes, to consider this type of shock for developed economies in which the crisis originated can be a strong reduced-form representation of a shock that propagated from a severe financial distortion, although it has been used anyway for the analysis, for instance, by Cúrdia and Woodford (2009) and many that followed their work. This is a controversial strategy because, if a financial friction was what originated a preference toward more savings, to analyze it in a reduced form will likely have non-trivial consequences for the analysis of monetary policy. On the other hand, thinking about the impact of the crisis in many small open economies, this disturbance seems a more appropriate way of capturing what happened in many of these countries. Most of these economies did not suffer a deep financial stress as in developed economies like the United States or the United Kingdom, and the shock more likely propagated from a precautionary saving motive which can be more properly captured by this type of disturbance.

[35] Given the calibration, this shock represents a drop close to 1,400 basis points in the real interest rate of the flexible-price equilibrium—i.e., in the baseline calibration, the steady-state real rate is 0.84 percent and the shock lowers it on impact to a value of −13.6 percent (all these figures are quarterly).

complementary policy. The solid line shows the case when the policy rate is allowed to be negative, as indicated by equation (9), while the dashed-dotted line considers a truncated Taylor rule, i.e., $i_t^{MP} = max\{-i, i_t^{target}\}$ where i is the steady-state value of the policy rate and $i_t^{target} = \rho_i i_{t-1}^{MP} + (1-\rho_i)(\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t)$. Therefore, the second alternative represents the case in which the zero bound is attained endogenously. As can be seen, when the zero bound is not accounted for, the shock produces a strong contraction on output,[36] a significant reduction in inflation, and both real and nominal depreciations.[37] The policy rate drops on impact and goes below the zero bound after the first period, remaining at a negative value for six quarters.

On the other hand, with the truncated Taylor rule the results are quite different: output drops even more, the deflation experienced is larger and starts on impact, and the nominal exchange rate displays an appreciation. It is also interesting to notice that the policy goes down to zero on impact, while in the previous case the rate was negative only after one quarter. This happens because agents internalize the presence of the zero bound, which—combined with the persistence of the shock—yields this equilibrium response.[38] Notice also that this anticipation generates that, in equilibrium, the policy rate under the truncated rule starts to rise earlier than the point in which the rate is positive in the equilibrium with no lower limit. Finally, the behavior of the ex ante real rate is also markedly different: at the zero bound, the shock increases the real rate, a result in line with the closed-economy analysis in Eggertsson and Woodford (2003) and akin to Keynes' Paradox of Thrift. In addition, in the open-economy case the negative effect generated by the appreciation seems to also contribute to this more severe recession.

The first unconventional policy we consider in this context is a temporary departure from the truncated Taylor rule in which the CB announces, right after the shock hits the economy, a decrease of

[36] In the robustness section we consider a model with habits, which significantly dampens the effect on output.

[37] Inflation does not drop on impact due to the presence of indexation in the Phillips curve and because of the nominal depreciation.

[38] Notice that the algorithm allows for the possibility that the zero bound is not attained on impact, but at a later period. However, this alternative does not correspond to an equilibrium in this case.

the policy rate down to zero and that it will be maintained there for a given number of periods (which is the same exercise considered in the previous subsection). Figure 17 displays this alternative for five, six, and seven quarters, and it also replicates the previous two cases for comparison. The results indicate that keeping the rate at zero for a longer period significantly reduces the problem originated by the zero bound, and if kept fixed long enough, it can even improve the responses obtained when the policy rate is allowed to be negative. The key channel for this result is the reaction of the real rate: as the policy rate is lower for a longer period of time, inflation expectations will rise. Nevertheless, while not shown for this case, the warnings regarding the credibility of the announcement analyzed in the previous subsection (figure 15) continue to apply here as well: the effect of the announcement will be milder if agents assign a positive probability to an earlier return to the truncated rule.

We analyze next the virtues of a purchase of foreign assets financed by money creation that is announced right after the shock materializes, and we consider the alternative only in the case of a truncated Taylor rule.[39] This is analyzed in figure 18. While the effect of absorbing the negative impact on output is only moderate, this policy helps to reduce (relative to the truncated rule) the deflation on impact by almost a half. The channel playing a relevant role in this case seems to be the wedge in the UIP equation: on one hand, it helps by almost eliminating the nominal appreciation on impact while, on the other hand, it worsens the situation by generating an expected appreciation (and therefore also a further deflation) which increases the real rate on impact.[40]

Finally, we consider the alternative of purchasing long-term debt financed by new short-term debt, which is displayed in figure 19.

[39] Because the size of the responses obtained after a negative shock are much larger than those explored when analyzing these alternative before, we increased the size of the operations analyzed to represent 50 percent of nominal GDP in steady state.

[40] In particular, if we set $\varphi_s = 0$, the nominal appreciation would be on impact smaller but, because no further appreciation would be expected, the increase in the real rate would be milder. Overall, the negative response of inflation would be reduced by just 2 percentage points, compared with almost 4 percentage points when φ_s takes the estimated value.

As expected given the results in subsection 3.2, although this operation improves the situation, its impact is of an order of magnitude smaller and therefore the differences are not noticeable. Nevertheless, we should stress the point highlighted also in that section: this alternative will probably not suffer the problems associated with the future expected behavior of the policy rate that are indeed relevant for alternatives that act through the liquidity channel.

3.6 Robustness

As a final exercise, we check the robustness of the results with respect to some parameter values. In particular, we first explore how the analysis presented in subsection 3.2 is affected by alternative values for the parameter describing the estimated frictions (plausible according to their estimated confidence bands) and also in terms of the coefficient in the Taylor rule that is assumed to follow after the temporary fix in i_t^{MP}.

Figure 20 shows the case of a purchase of foreign assets financed by a monetary expansion when the policy rate is fixed for six periods, presenting the case of the original value for φ_m (−0.0014), as well as two other alternatives representing plus and minus one standard error of the estimated parameter (−0.0007 and −0.0021). As can be seen, these differences in the coefficient affecting the liquidity channel significantly change the impact of this policy, particularly in terms of the responses of output and the real exchange rate and, to a lesser extent, in terms of inflation and nominal depreciation.

On the other hand, figure 21 presents the alternative of a purchase of long debt financed with new short debt under different values of the parameter φ_k (0.017, the point estimate, as well as 0.019 and 0.015—i.e., plus and minus two standard errors, respectively). In this case, changes in this parameter within its confidence range do not significantly affect the original responses.

We also check the robustness regarding the parameters describing the Taylor rule that will be in place after the temporary fix in the policy rate. Because agents anticipate the contractionary policy that will follow once the Taylor rule returns, the expansion generated by the unconventional policy will be smaller the more aggressive the response is with respect to inflation and output deviations, and the less important the smoothing part of the rule is. Accordingly, figure 22 displays the result of a purchase of foreign assets financed by a monetary expansion when the policy rate is fixed for six periods, considering the original Taylor rule as well as three alternative coefficients: half the response to the previous interest rate, and double the reaction to either inflation or output. As can be seen, it appears that these alternative rules affect mainly the response of output and, to a lesser extent, those of inflation and the real exchange rate.

Similarly, figure 23 shows the impact that considering the same alternative rules has on the evaluation of purchasing long debt financed with new short debt, also fixing the policy rate for six periods. In this case, the different specifications of the rule had little impact on the responses of output and inflation, while affecting more the responses of the real exchange rate and the ex ante real interest rate.

In addition, figure 24 evaluates the role of the Taylor rule's parameters for the experiment of driving the policy rate to zero for some time (subsection 3.4). For this case, what appears to generate significant difference is the smoothing coefficient, particularly for output and the real exchange rate, which was expected because this parameter will dictate how fast the interest rate can rise once the lower bound is abandoned.

As a final exercise related to subsection 3.5, we consider a model that includes exogenous habit formation in consumption. We do this for two reasons. First, this alternative will dampen the size of the recession, which (particularly in terms of GDP) seems excessive in the benchmark model. Second, the persistence of all variables will increase and therefore the zero limit will likely bind for a longer period. In particular, we set a habit parameter to 0.7, in line with previous estimates for Chile (e.g., Medina and Soto 2007). Figure 25 is analogous to figure 17 using this alternative model. Comparing both figures, the effects on output and inflation in the baseline case of no zero bound are indeed quantitatively smaller and more persistent. In terms of the policy rate, in this case it goes below zero after the third quarter. Nevertheless, it is still the case that the anticipation in the truncated-rule case generates a more severe recession and deflation, implying an equilibrium where the policy rate drops to zero right after the shock hits and then stays there endogenously for six quarters. Finally, in terms of policies that keep the rate at zero for a longer period, we can observe a qualitatively similar ranking of the responses; however, the quantitative differences between each of them are larger.

4. Conclusions

This paper uses a New Keynesian model of a small open economy to provide a quantitative evaluation of different policy alternatives that a CB can use when the nominal interest rate is fixed. In particular, we have analyzed the effects of different changes in the CB balance sheet, such as movements in the holdings of foreign assets, base money, and debt at different maturities. To allow for the possibility of the CB changing these assets, the standard model was extended to include several frictions—namely, a liquidity premium, deviations from the UIP condition, and a premium in the term structure of interest rates. Additionally, we introduced an algorithm that allows us to take into account issues like the anticipation of future policies, the (exogenous) lack of credibility in the announcements, and the role of the zero bound.

The results show that policies working through the liquidity channel can potentially have important expansionary effects, although their impact greatly depends on the perception about the future path of the interest rate and its credibility. On the other hand, policies aimed at reducing the term premium, while generating smaller expansions, are less dependent on the expected behavior of the policy rate and on credibility issues. Additionally, it seems that reversing the unconventional policy as a possible exit strategy might not be beneficial, particularly if these changes are anticipated. Finally, we described how driving the policy rate down to its lower bound and maintaining it at that value for some time can be highly expansionary as well, although the issues regarding the credibility of the announcement are also relevant in this case.

It is useful to compare these results with those in Eggertsson and Woodford (2003). Using a simpler model (in particular, a closed economy), their analysis suggests that the channel that is relevant to escape from a zero-bound situation is to affect the expectations about future inflation. Moreover, they show that the optimal policy in such a situation is a price level target. In our case, although we are not characterizing the optimal policy, we have described that the potentially big effect generated by policies affecting the liquidity premium is due to the increase in the future price level brought about by the permanent increase in base money, resembling the channel emphasized by these authors. Additionally, they also highlight that the effectiveness of this policy depends on the credibility of the announcement.[41]

It is also worth mentioning that, although in our setup money is what helps reduce the liquidity premium, there is nothing exclusively special about money. Actually, in more general settings where other assets can affect this premium (for instance, it might be the case that short-run debt provides liquidity as well), a permanent increase in such an asset can also generate the same effect, and its importance will also be subject to the same caveats about the expected path of interest rates and credibility that we have analyzed.

Additionally, it is worth mentioning that unconventional monetary strategies might not necessarily be the only (nor the most effective) policy alternatives available to use in a zero-bound situation. In particular, there are several fiscal tools that can be used as well. For instance, Christiano, Eichenbaum, and Rebelo (2009) describe that the government-expenditure multiplier is actually quite large when the nominal interest rate is at its lower bound. Additionally, Eggertsson (2006) highlights that government debt can be used as a commitment device to ameliorate the credibility issues associated with the optimal monetary policy. Our goal, however, was to analyze the virtues of these monetary alternatives, and we left the interaction with fiscal tools for future research.[42]

Finally, an important extension that is left for future research is to rank the different alternatives from the point of view of optimal policy. However, as we have argued, this is the kind of exercise in which having a more precise microfoundation of the different channels is most relevant. Nevertheless, this study shed light on the aspects of the model that might be more relevant to consider.

[41] Eggertsson (2006) formally discusses the issues of credibility arising from this optimal policy.

[42] Moreover, in terms of the country we chose for the application, Chile has had a fiscal rule in place since 2001, limiting the fiscal deficits according to the revenues from copper exports. This characteristic places a bound on the type of fiscal tools that can be implemented, which further emphasizes the importance of analyzing the monetary alternatives.

Appendix 1. Technical Appendix

The Lower Bound, Anticipating Policy Changes, and Credibility in Linear Rational Expectations Models

Here we describe the algorithm to compute the policy exercises in the paper.[43] In a contemporaneous work, Bodenstein, Erceg, and Guerrieri (2009) present a similar algorithm, considering how to compute impulse responses when, given an initial shock, the interest rate reaches the lower bound endogenously through the Taylor rule. Here, we additionally consider the possibility that the central bank chooses (exogenously, as a policy) to fix the interest rate, deviating from the Taylor rule, to a given value (possibly zero) for a certain period of time. Moreover, we allow agents to assign an exogenous probability to the central bank breaking its promise and returning to the usual rule before it was announced. We also show how to compute the equilibrium trajectories when the unconventional policy is reversed, either surprisingly or anticipated.

The first exercise we want to consider is when the central bank announces, at time t_0, that the interest rate is going to stay at the lower bound until period $t_1 - 1$, and starting at t_1 the rate will be determined by the Taylor rule. The Taylor rule in "normal times" is constrained by the lower bound, so that the policy rate (measured as deviations from steady state) is

$$i_t = max\{-i, i_t^{target}\}, \tag{10}$$

where i is the steady-state value of the policy rate and the targeted policy rate is a linear function of any variable in the model (for instance, $i_t^{target} = \phi_i i_{t-1} + \phi_\pi \pi_t + \phi_y y_t$).[44] In particular, this implies that, even though the central bank can guarantee to keep the interest rate at the lower bound up to period $t_1 - 1$, the state of the economy could be such that the target rate is below $-i$ at t_1. Therefore, because the algorithm works with the idea of backward induction, we first describe how to compute the equilibrium for a given initial value of the state variables and the exogenous process

[43] Although we focus on applying the technique for the case analyzed in the paper, notice that this method is quite general and can accommodate many examples in these lines.

[44] It is, however, assumed that the constraint doesn't bind at the steady state.

when the policy rate is determined by the rule (10) (i.e., when the zero bound binds endogenously), and then we explore the solution for the period in which the government sets the policy rate at the lower bound (i.e., when the zero bound is imposed exogenously, as a policy choice).

At any point in time in which the $i_t = i_t^{target}$ endogenously, the conditions characterizing a linear rational expectations equilibrium can be written as

$$AE_t\{z_{t+1}\} = Bz_t + Cz_{t-1} + De_t, \tag{11}$$

where z_t is a vector collecting endogenous variables (including i_t and i_t^{target}), e_t is exogenous driving forces following the process $e_t = \rho e_{t-1} + u_t$, u_t is a vector of i.i.d random disturbances with zero mean, and A, B, C, and D are conformable matrices describing the linearized equilibrium conditions. In particular, if n_1 denotes the position in the vector z_t of the variable i_t and n_2 is analogous to the variable i_t^{target}, there is an equation j in the system such that (using Matlab notation) $A(j, :) = C(j, :) = D(j, :) = 0$ while $B(j, n_1) = -1$, $B(j, n_2) = 1$, and $B(j, l) = 0$ for $l \neq \{n_1, n_2\}$. On the other hand, when $i_t = -i$, the equilibrium is characterized by the system

$$AE_t\{z_{t+1}\} = \tilde{B}z_t + Cz_{t-1} + De_t + c, \tag{12}$$

where $\tilde{B}$ differs from B only in that $\tilde{B}(j, n_2) = 0$ and c is a column vector full of zeros except in position j where $c(j) = -i$.

The algorithm works under the assumption (which we later discuss) that if, starting at any given period t_1, there is a period $t \geq t_1$ such that $i_t = i_t^{target}$, then $i_{t+j} = i_{t+j}^{target}$ for $j > 0$ (i.e., if at some point the constraint on the interest rate ceases to bind, it will not bind again after that). Let T denote the minimum $t \geq t_1$ such that the constraint is no longer binding (i.e., $i_t = i_t^{target}$ for $t \geq T$ and $i_{T-1} = -i$) and assume for the moment that T is known. Therefore, the solution characterizing the equilibrium for $t \geq T$—obtained using the usual techniques—can be written as

$$z_t = F_T z_{t-1} + G_T e_t. \tag{13}$$

At period $T - 1$ the policy rate is at the lower bound and the equilibrium is characterized by (12). Moreover, because agents know at T, $i_T = i_T^{target}$, they will use (13) to form expectations, i.e., $E_{T-1}\{z_T\} = F_T z_{T-1} + G_T \rho e_{T-1}$. Therefore, we can write the equilibrium conditions at $T-1$ as

$$A(F_T z_{T-1} + G_T \rho e_{T-1}) = \tilde{B} z_{T-1} + C z_{T-2} + D e_{T-1} + c, \tag{14}$$

which can be rearranged to obtain

$$\begin{aligned} z_{T-1} &= (AF_T - \tilde{B})^{-1} C z_{T-2} + (AF_T - \tilde{B})^{-1}(D - AG_T \rho) e_{T-1} \\ &\quad + (AF_T - \tilde{B})^{-1} c, \\ &\equiv F_{T-1} z_{T-2} + G_{T-1} e_{T-1} + H_{T-1} c, \end{aligned} \tag{15}$$

provided $AF_T - \tilde{B}$ is invertible. Working in this same way backwards until t_1, we can compute the equilibrium for $t \in [t_1, T-1]$, which will have the form

$$z_t = F_t z_{t-1} + G_t e_t + H_t c,$$

where

$$\begin{aligned} J_t &\equiv (AF_{t+1} - \tilde{B})^{-1}, \\ F_t &\equiv J_t C, \\ G_t &\equiv J_t (D - AG_{t+1} \rho), \\ H_t &\equiv J_t(-AH_{t+1} + I) \text{ for } t \in [t_1, T-2],\ H_{T-1} \equiv (AF_T - \tilde{B})^{-1}. \end{aligned} \tag{16}$$

Therefore, using these matrices, for initial values of z_{t_1-1} and e_{t_1-1} we can obtain the perfect foresight path (impulse response) for a given shock u_{t_1}, under the assumption that T is known. To find T, we can just run a progressive search starting on t_1 and find the first period for which $i_T = i_T^{target}$ and $i_{T-1} = -i$.

Before moving to the case in which the central bank imposes the lower bound, two comments are in order. First, notice that once T is found, the assumption that $i_t = i_t^{target}$ for $t \geq T$ can be verified numerically by simulating the path for the variables for many periods beyond T (by construction, the assumption will hold in steady state). Second, the extension for the case in which, given values z_{t_1-1} and u_{t_1}, the lower bound is expected to be reached in a period after t_1 is straightforward, which in our case is particularly relevant to check when analyzing the response of a contractionary shock in subsection 3.5.

To consider the case in which the central bank announces, at time t_0, that the interest rate is going to stay at the lower bound until period $t_1 - 1$, and starting at t_1 the rate will be determined by the Taylor rule, notice that the matrices in (17) characterize any backward induction problem in which the policy rate is expected to be at the lower bound for a certain period of time. Therefore, given an announced period t_1 and an initial shock u_{t_0}, we can proceed as follows. First, assuming that $T = t_1$ (i.e., that after the period the central bank has announced the state of the economy is such that the constraint on the policy rate is not binding), compute the matrices characterizing the equilibrium according to (17) and numerically verify whether $i_t = i_t^{target}$ for $t \geq t_1$ or not. If that is not the case, increase the candidate value for T until the condition is satisfied.[45]

We can also consider the role of exogenous credibility. In particular, we assume that in every period $t \in [t_0, t_1 - 2]$ when the interest rate is fixed, people assign a probability sequence p_t to the event that the central bank breaks its promise and sets the nominal interest rate according to the Taylor rule starting at $t + 1$. Moreover, if this is the case, they believe that the Taylor rule will stay forever. Additionally, regardless of people not trusting the central bank, we assume that (ex post) it fulfills its promises.

This possibility is accommodated by simply modifying the equations in (17) to obtain

$$\begin{aligned}
J_t &\equiv [A(p)tF_{t_1} + (1 - p_t)F_{t+1}) - \tilde{B}]^{-1}, \\
F_t &\equiv J_t C, \\
G_t &\equiv J_t[D - A(p_t G_{t_1} + (1 - p_t)G_{t+1})\rho], \\
H_t &\equiv J_t[-A(1 - p_t)H_{t+1} + I] \text{ for } t \in [t_0, t_1 - 2], \\
H_{t_1 - 1} &\equiv (AF_{t_1} - \tilde{B})^{-1}.
\end{aligned}$$

Finally, to consider an unconventional policy in t_0, we just assign values at t_0 for the shocks affecting the different instruments in the

[45]Notice that if we want to consider fixing the interest rate not at zero but to any arbitrary value, this can be done by setting an appropriate value for the constant c.

central bank's balance sheet. Additionally, the alternative of undoing these policies is also considered by placing appropriate values for the sequence u_t: if the change is not pre-announced we just change the value in the corresponding period, and if the change is pre-announced we can expand the exogenous vector e_t to consider anticipated shocks.

The Model

Here we present the equilibrium conditions of the model, as well as the calibration of the parameters. It is a standard New Keynesian model for a small open economy with incomplete asset markets. Households have separable preferences in consumption and leisure and can transfer resources over time using an internationally traded bond, as well as the debt created by the central bank. They consume a combination of domestic and foreign goods. There is an infinite number of monopolistic intermediate goods firms that use labor to produce using a constant returns to scale technology. They are subject to a Calvo-type problem in setting prices, with full indexation to past inflation. The equilibrium conditions associated with household optimization are[46]

$$\lambda_t = (c_t - bc_{t-1})^{-\sigma}, \tag{17}$$

$$w_t = \phi_0 l_t^{\phi_1} c_t^{\sigma}, \tag{18}$$

$$\lambda_t = \beta v_t i_{1,t} E_t \left\{ \frac{\lambda_{t+1}}{\pi_{t+1}} \right\} \left(\frac{D_{k,t}^{BC} / D_k^{BC}}{D_{1,t}^{BC} / D_1^{BC}} \right)^{\varphi_k}, \tag{19}$$

$$\lambda_t = \beta v_t i_t^* cp_t E_t \left\{ \frac{S_{t+1}\lambda_{t+1}}{S_t \pi_{t+1}} \right\} \left(\frac{B_t^{*BC}}{B_{t-1}^{*BC}} \right)^{\varphi_s}, \tag{20}$$

$$c_t = \left[(1-a)^{\frac{1}{\eta}} \left(c_t^H \right)^{\frac{\eta-1}{\eta}} + (a)^{\frac{1}{\eta}} \left(c_t^F \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}. \tag{21}$$

[46] Variables without time subscripts denote steady-state values. Prices have been rescaled by the price index. Recall that in the case of (19), (20), and (24), which display the deviations from the standard model, these are imposed ad hoc over the usual equilibrium conditions and are not derived from microfoundations.

$$c_t^F = a\left(p_t^F\right)^{-\eta} c_t, \tag{22}$$

$$c_t^H = (1-a)\left(p_t^H\right)^{-\eta} c_t, \tag{23}$$

$$\frac{i_{1,t}}{i_t^{MP}} = \left(\frac{M_t}{P_t y_t}\frac{Py}{M}\right)^{-\varphi_m}. \tag{24}$$

Those related to firms' choices are[47]

$$y_t^H = z_t l_t - \kappa, \tag{25}$$

$$mc_t = \frac{w_t}{p_t^H z_t}, \tag{26}$$

$$f_t^1 = mc_t\left(\tilde{p}_t^H\right)^{-\epsilon} y_t^H + \theta\beta E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\pi_t}{\pi_{t+1}}\right)^{-\epsilon}\left(\frac{\tilde{p}_t^H}{\tilde{p}_{t+1}^H}\right)^{-\epsilon}\left(\frac{p_t^H}{p_{t+1}^H}\right)^{-1-\epsilon} f_{t+1}^1\right\}, \tag{27}$$

$$f_t^2 = \left(\tilde{p}_t^H\right)^{1-\epsilon} y_t^H\left(\frac{\epsilon-1}{\epsilon}\right) + \theta\beta E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\pi_t}{\pi_{t+1}}\right)^{1-\epsilon}\left(\frac{\tilde{p}_t^H}{\tilde{p}_{t+1}^H}\right)^{1-\epsilon}\left(\frac{p_t^H}{p_{t+1}^H}\right)^{-\epsilon} f_{t+1}^2\right\}, \tag{28}$$

$$f_t^1 = f_t^2. \tag{29}$$

The conditions associated with rest-of-the-world variables are

$$cp_t = \psi_d\left(e^{-p_t^F b_{t+1}^* + \bar{b}} - 1\right), \tag{30}$$

$$\frac{p_t^F}{p_{t-1}^F} = \frac{S_t \pi_t^*}{S_{t-1}\pi_t}, \tag{31}$$

[47]The assumption of full indexation to past inflation yields that, up to first order, the distortion that, in principle, price stickiness introduces (i.e., a gap between production and absorption) is not relevant even if steady-state inflation is different from zero.

Table 1. Calibration

σ	1	ϕ_1	0.84	a	0.34
η	1.12	ϵ	11	η^*	0.79
θ	0.74	ψ_d	0.01	μ_m	0.2
ρ_i	0.74	α_π	1.67	α_y	0.39
i^*	1.0025	i	1.016	π	1.0074
l	0.2	$\frac{D_1^{CB}+D_k^{CB}}{M}$	1.8	$\frac{D_k^{CB}}{D_1^{CB}}$	0.8

$$c_t^{H*} = \left(\frac{p_t^H}{p_t^f}\right)^{-\eta^*} y_t^*. \tag{32}$$

Market clearing conditions are

$$1 = \theta\left(\frac{p_{t-1}^H \pi_{t-1}}{p_t^H \pi_t}\right)^{1-\epsilon} + (1-\theta)\left(\tilde{p}_t^H\right)^{1-\epsilon}, \tag{33}$$

$$y_t^H = c_t^H + c_t^{H*}, \tag{34}$$

$$y_t = c_t + p_t^H c_t^{H*} - p_t^F c_t^F, \tag{35}$$

$$tb_t = p_t^H c_t^{H*} - p_t^F c_t^F, \tag{36}$$

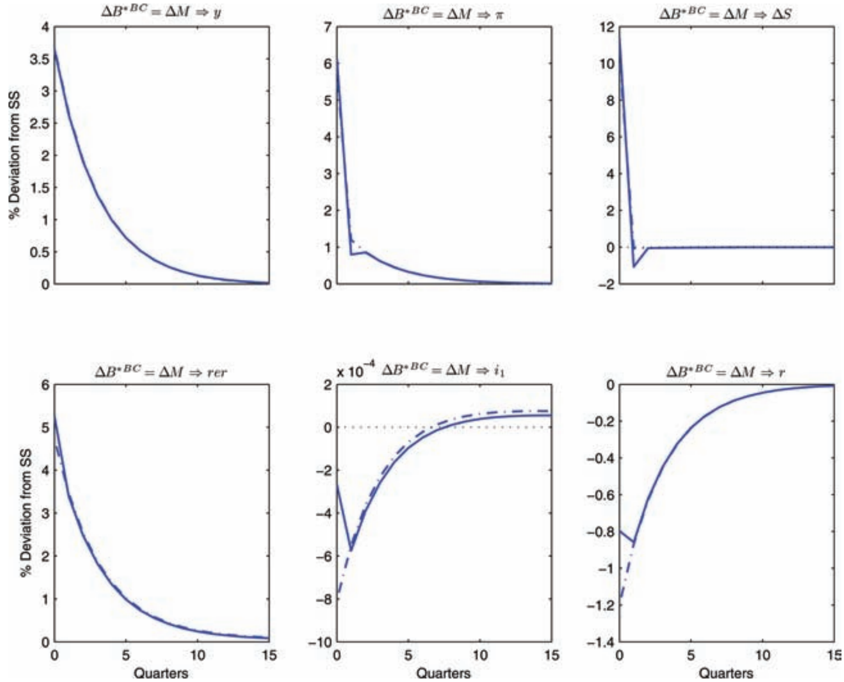
$$p_t^F b_{t+1}^* = p_t^F \frac{b_t^*}{\pi_t^*} i_{t-1}^* cp_{t-1} + tb_t. \tag{37}$$

Finally, monetary policy is as described in the text.

We calibrate the parameters following the structural estimation for Chile performed by Medina and Soto (2007), and the steady-state ratios of the variables in the CB balance sheet are taken from the average of the series used for estimation described in the text. The time period is meant to be a quarter. Table 1 presents the parameters and steady-state variables that were calibrated. Also, in the baseline version we consider no habits ($b = 0$) while in the robustness section we set $b = 0.7$. Finally, we assume that the frictions disappear in steady state. This implies that we need to introduce a demand for real balances in steady state, which we choose to be $M/P = y(i)^{-\mu_m}$.

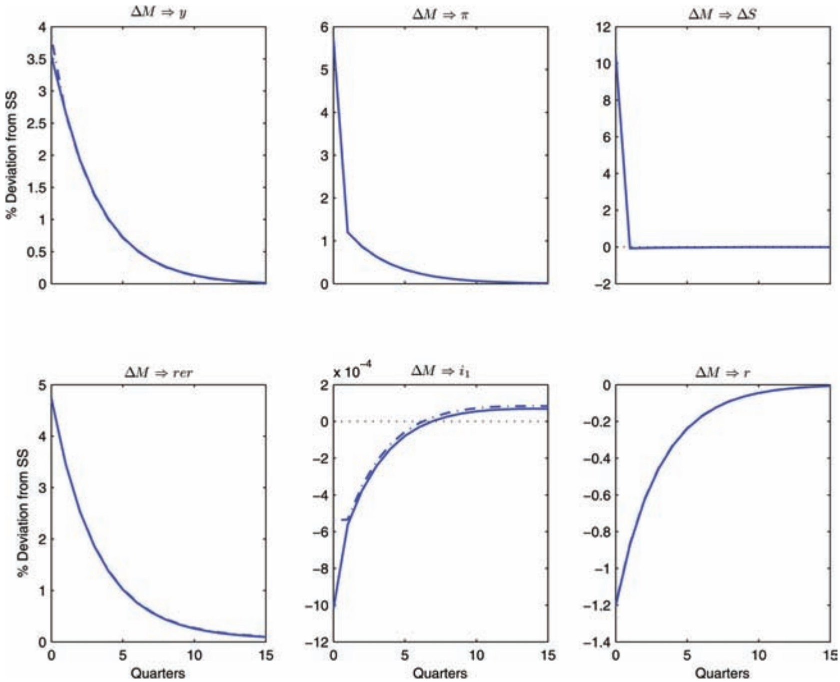
Appendix 2. Figures

Figure 1. Purchase of Foreign Assets Financed with a Monetary Expansion



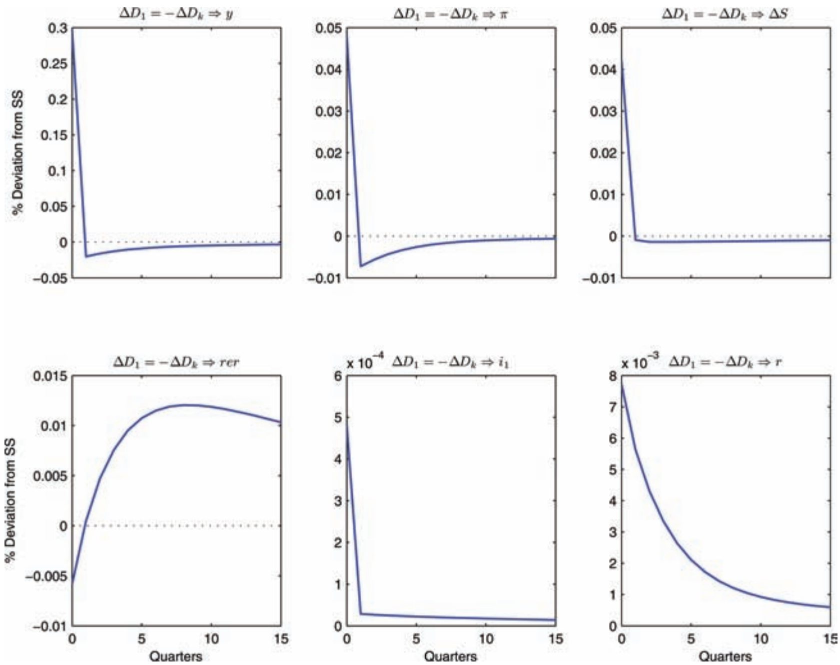
Note: y is real GDP, π is inflation, ΔS is nominal depreciation, rer is the real exchange rate, and $r_t \equiv i_{1,t} - E_t\pi_{t+1}$ is the ex ante real interest rate. All variables are in log-deviations from steady state. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value forever. The solid line is the benchmark case, while the dashed-dotted line is the case with $\varphi_d = \varphi_s = 0$.

Figure 2. Purchase of Debt Financed with a Monetary Expansion



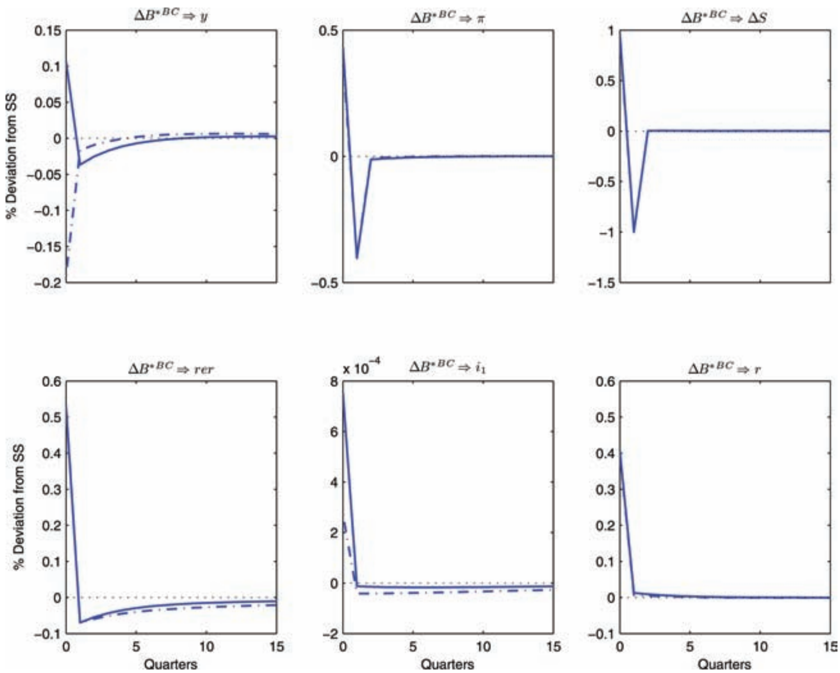
Note: The solid line corresponds to a purchase of short debt, $D_{1,t}$, and the dashed-dotted line is purchase of long debt, $D_{k,t}$. The shock is a permanent increase in M_t equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value forever.

Figure 3. Purchase of Long Debt Financed with New Short Debt



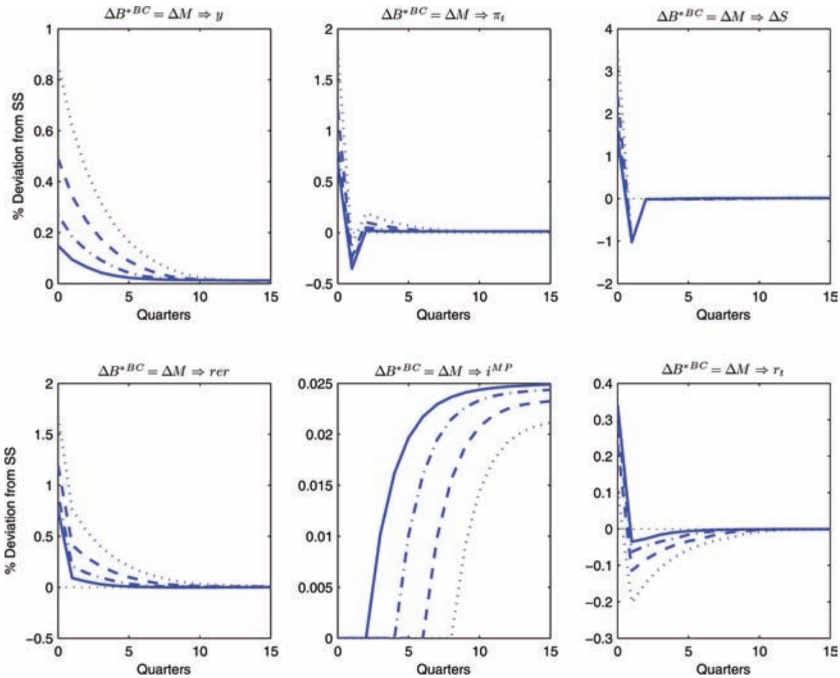
Note: The shock is a permanent increase in $D_{1,t}$ equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value forever.

Figure 4. Purchase of Foreign Assets Financed with New Debt



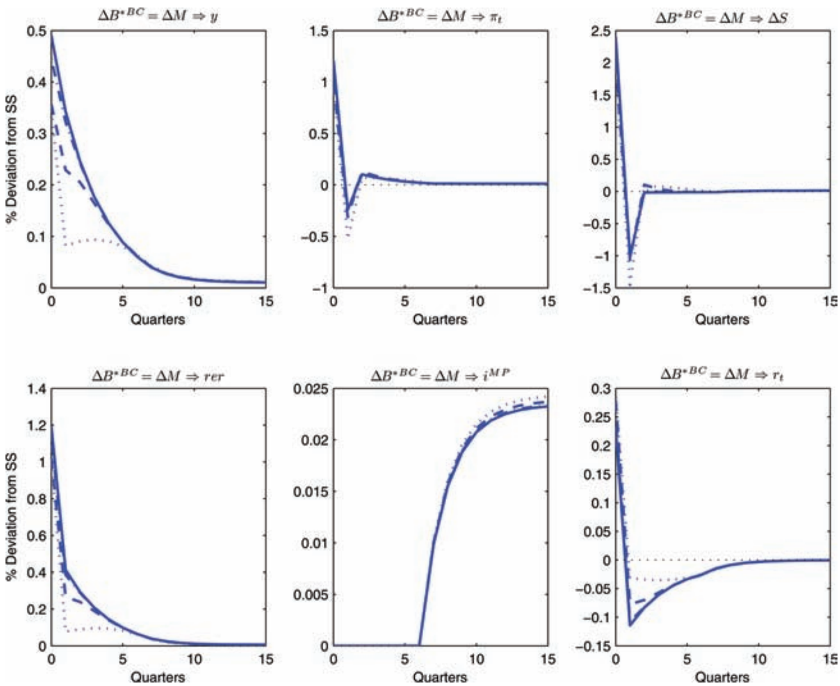
Note: The solid line corresponds to new short debt, $D_{1,t}$, and the dashed-dotted line is new long debt, $D_{k,t}$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value forever.

Figure 5. Purchase of Foreign Assets Financed with a Monetary Expansion: Different T's, $p_t = 0$



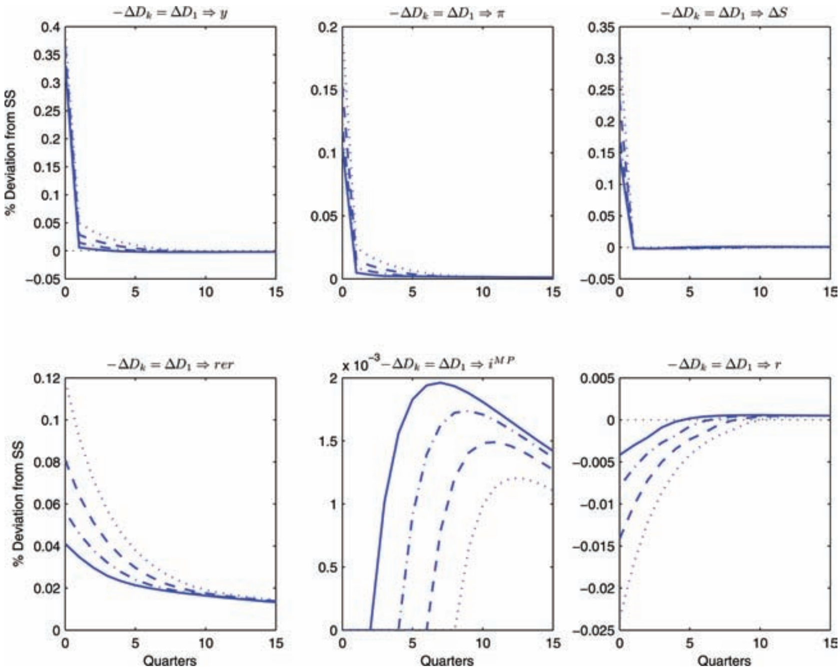
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $T = 2, 4, 6, 8$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 6. Purchase of Foreign Assets Financed with a Monetary Expansion: $T = 6$, $p_t = p^t$, Different p's



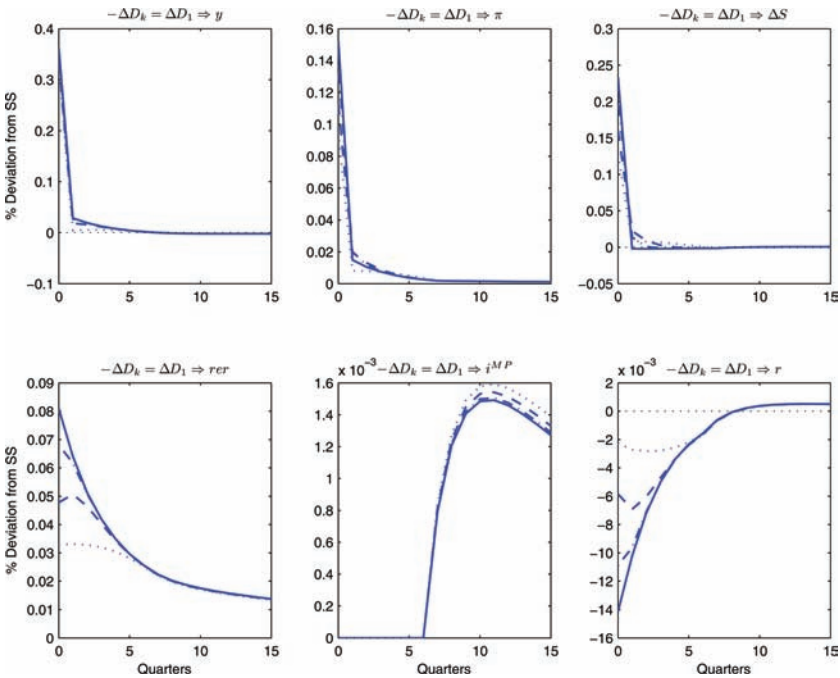
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $p = 0, 0.3, 0.6, 0.9$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 7. Purchase of Long Debt Financed with New Short Debt: Different T's, $p_t = 0$



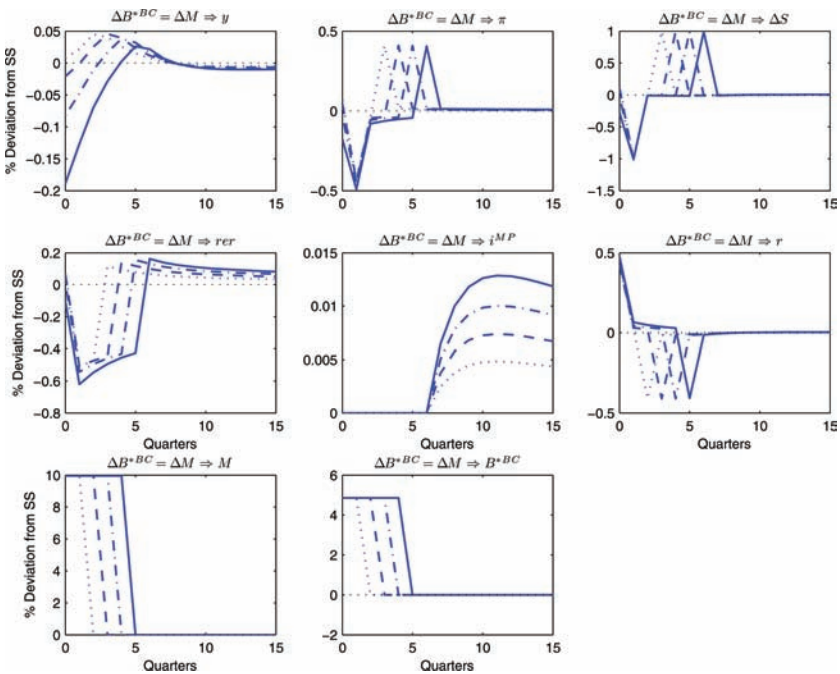
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $T = 2, 4, 6, 8$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 8. Purchase of Long Debt Financed with New Short Debt: $T = 6$, $p_t = p^t$, Different p's



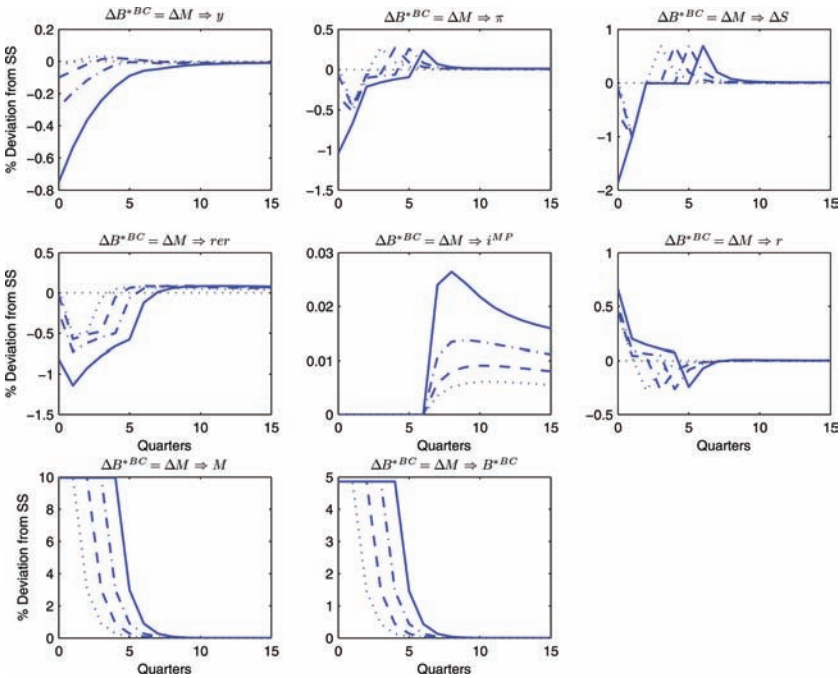
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $p = 0, 0.3, 0.6, 0.9$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 9. Purchase of Foreign Assets Financed with a Monetary Expansion, Pre-Announced Reversal, Different k's



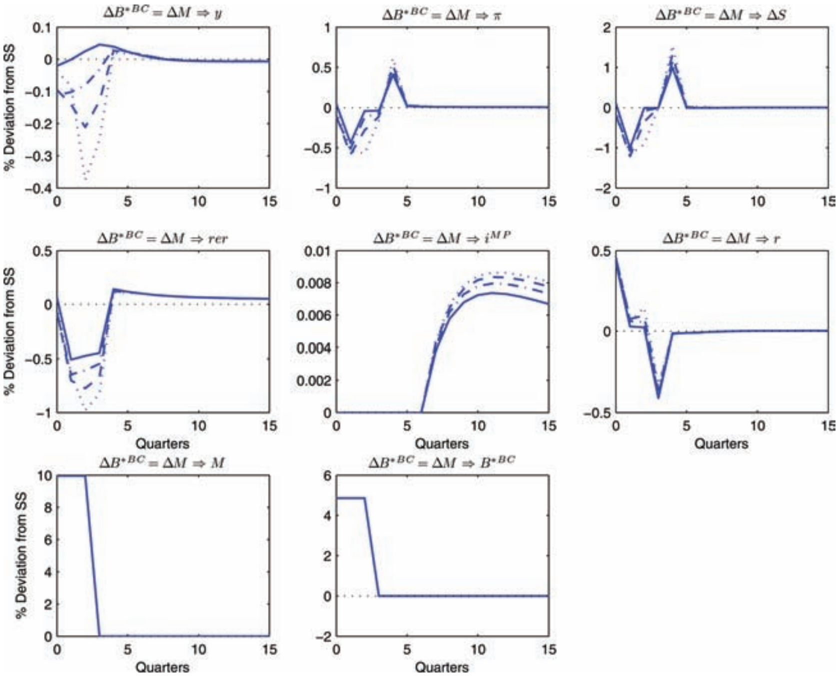
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $k = 2, 3, 4, 5$, with $T = 6$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, which is fully reversed in $T - k$, while i_t^{MP} remains in its steady-state value until T.

Figure 10. Purchase of Foreign Assets Financed with a Monetary Expansion, Pre-Announced Gradual Reversal, Different k's



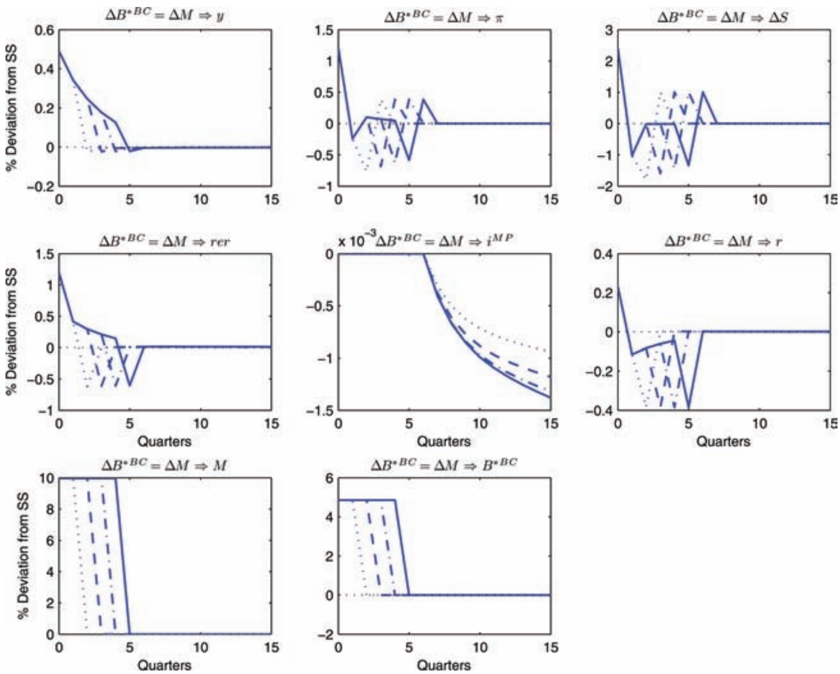
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $k = 2, 3, 4, 5$, with $T = 6$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, which is reversed slowly starting at $T - k$, while i_t^{MP} remains in its steady-state value until T.

Figure 11. Purchase of Foreign Assets Financed with a Monetary Expansion, Pre-Announced Reversal, $p_t = p^t$, Different p's



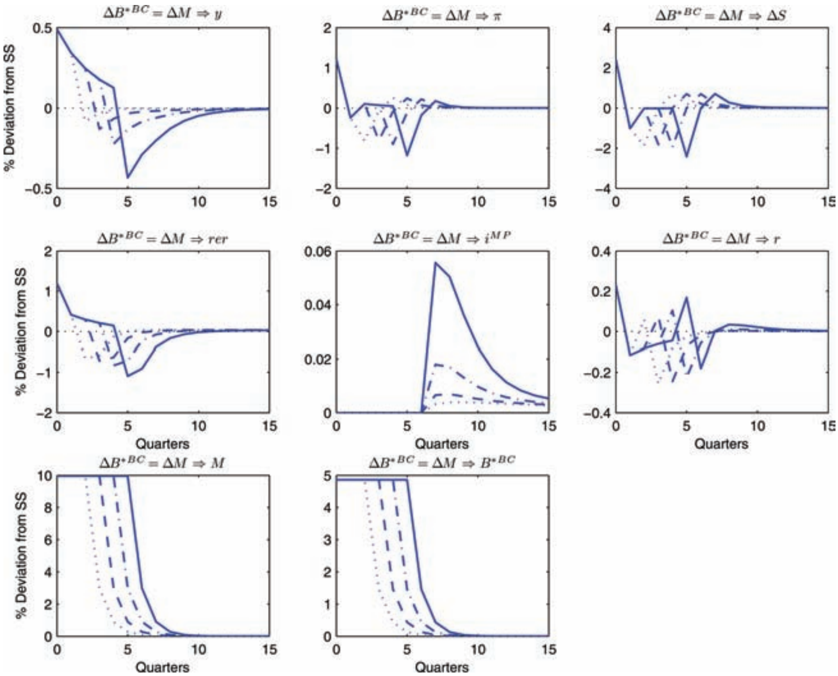
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $p = 0, 0.3, 0.6, 0.9$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, which is fully reversed in $T - k$, with $T = 6$ and $k = 4$, while i_t^{MP} remains in its steady-state value until T.

Figure 12. Purchase of Foreign Assets Financed with a Monetary Expansion, Unexpected Reversal, Different *k*'s



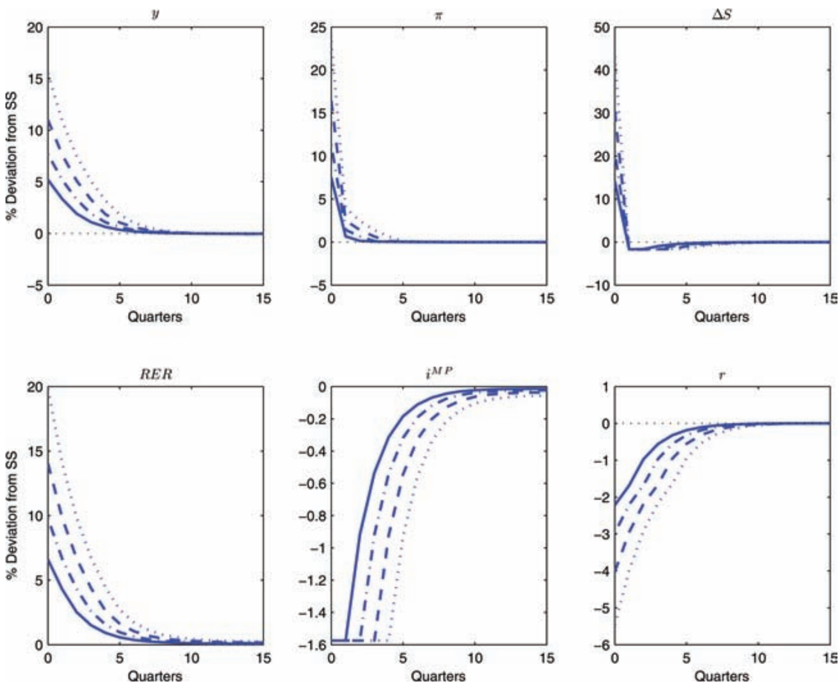
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $k = 2, 3, 4, 5$, with $T = 6$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, which is fully reversed in $T - k$ but is not anticipated, while i_t^{MP} remains in its steady-state value until T.

Figure 13. Purchase of Foreign Assets Financed with a Monetary Expansion, Unexpected Gradual Reversal, Different *k*'s



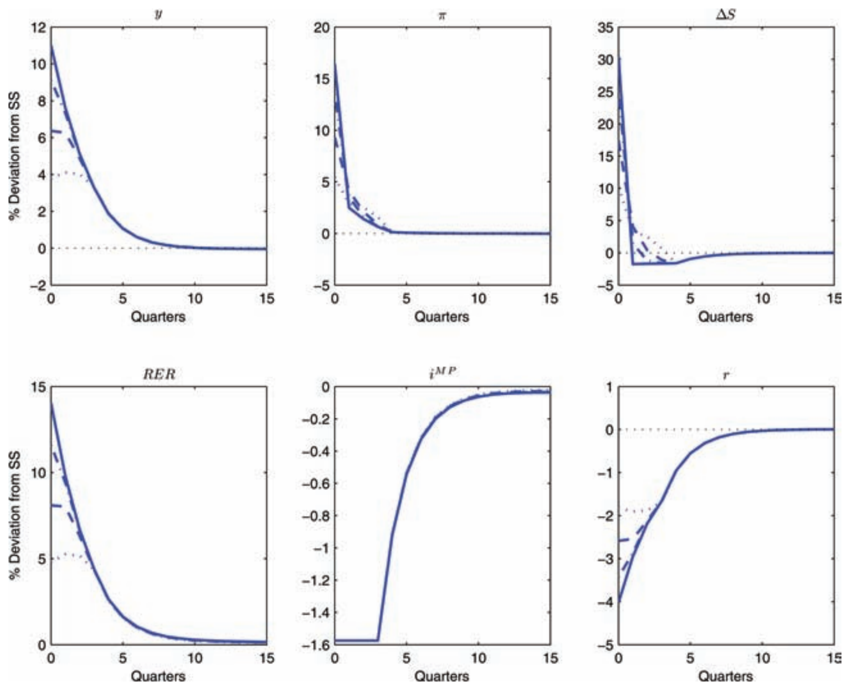
Note: The solid, dashed-dotted, dashed, and dotted lines correspond, respectively, to $k = 2, 3, 4, 5$, with $T = 6$. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, which is reversed slowly starting at $T - k$ but is not anticipated, while i_t^{MP} remains in its steady-state value until T.

Figure 14. Driving i_t^{mp} to Zero: Different T's, $p_t = 0$



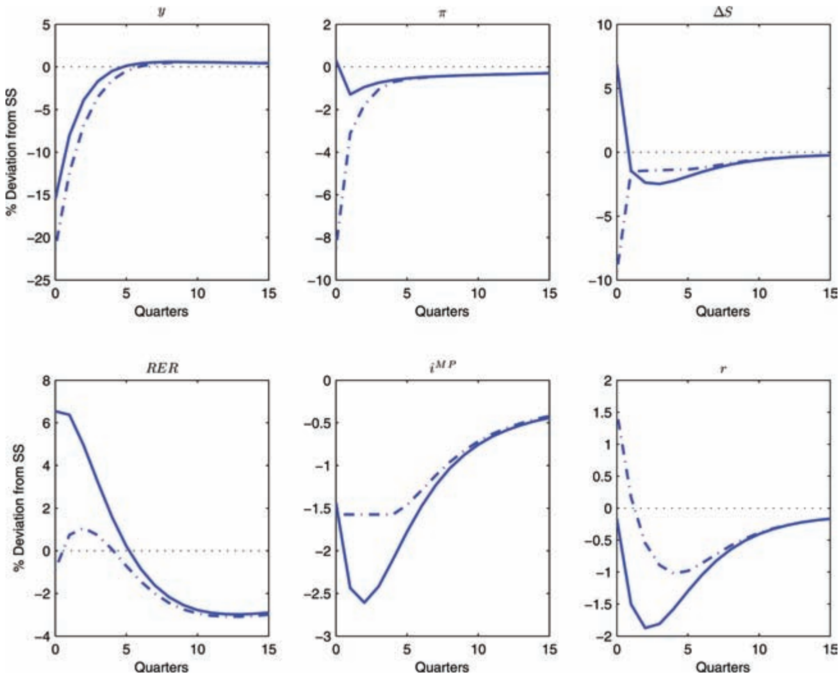
Note: The solid, dashed-dotted, dashed, and dotted lines correspond to the response of driving i_t^{MP} to zero and keeping it at this value until, respectively, $T = 1, 2, 3, 4$.

Figure 15. Driving i_t^{mp} to Zero: $T = 3$, $p_t = p^t$, Different p's



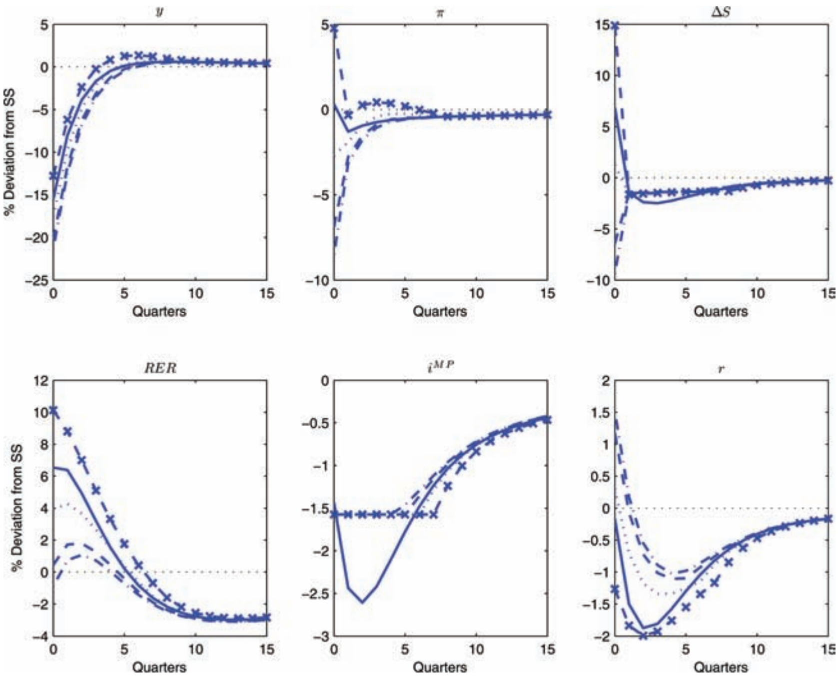
Note: The solid, dashed-dotted, dashed, and dotted lines correspond to the response of driving i_t^{MP} to zero and keeping it at this value until $T = 3$, with $p_t = p^t$ and, respectively, $p = 0, 0.3, 0.6, 0.9$.

Figure 16. The Effects of a Contractionary Shock Under Different Policy Rules



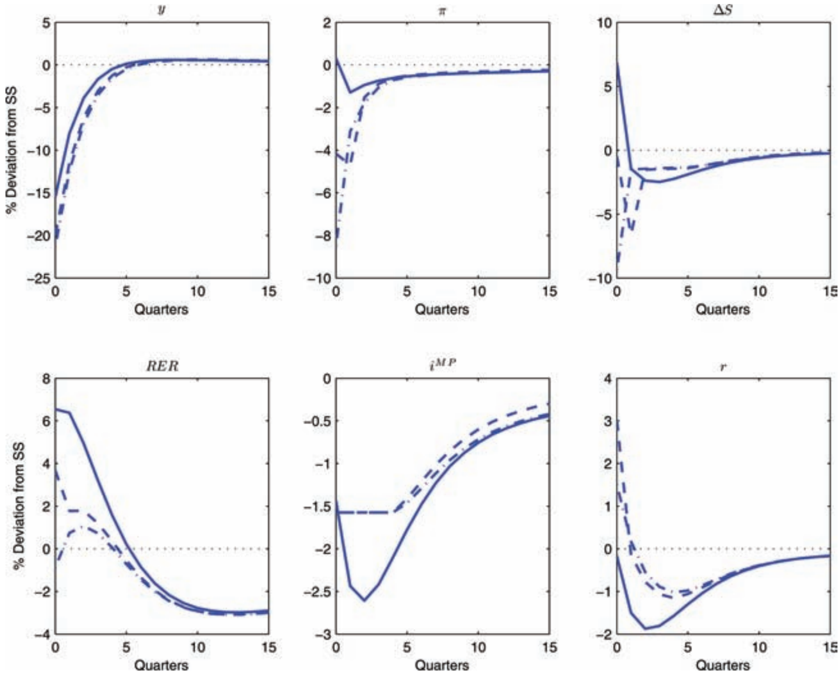
Note: The solid line shows the case when the policy rate is allowed to be negative, while the dashed-dotted line considers a truncated Taylor rule.

Figure 17. The Effects of a Contractionary Shock and Departures from the Taylor Rule



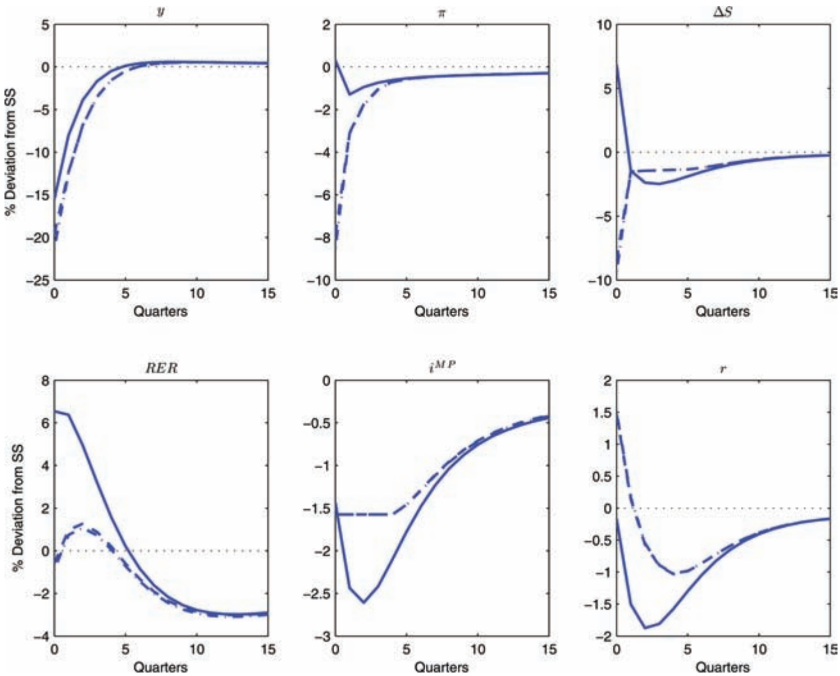
Note: The solid line shows the case when the policy rate is allowed to be negative; the dashed-dotted line considers a truncated Taylor rule; and the dashed, the dotted, and the crossed lines are the cases when i_t^{MP} is driven to zero and maintained at this value for, respectively, five, six, and seven quarters.

Figure 18. The Effects of a Contractionary Shock and Purchase of Foreign Assets Financed with a Monetary Expansion



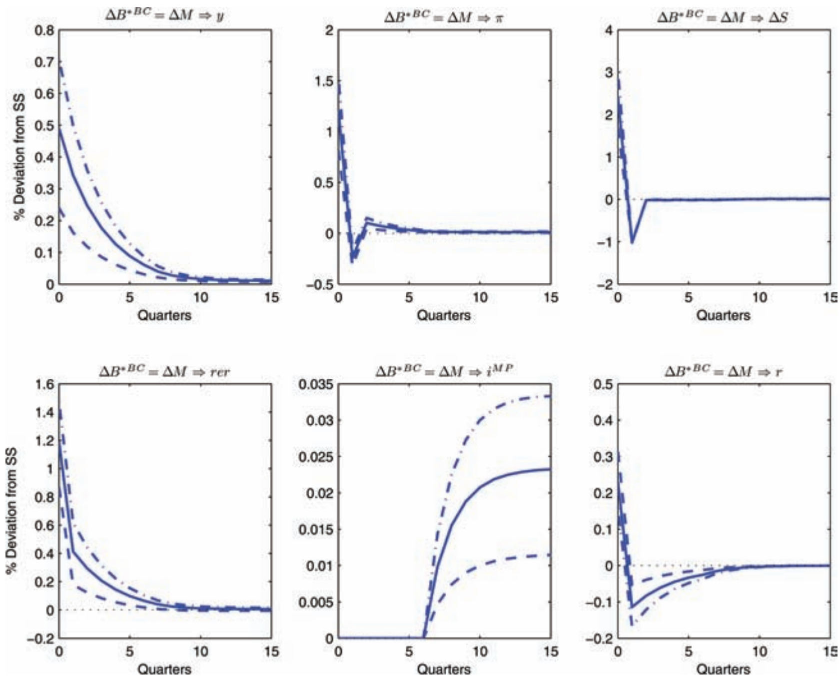
Note: The solid line shows the case when the policy rate is allowed to be negative, the dashed-dotted line considers a truncated Taylor rule, and the dashed line is the case of a truncated Taylor rule coupled with a purchase of foreign assets financed with a monetary expansion equivalent to 50 percent of the steady-state nominal GDP.

Figure 19. The Effects of a Contractionary Shock and Purchase of Long Debt Financed with New Short Debt



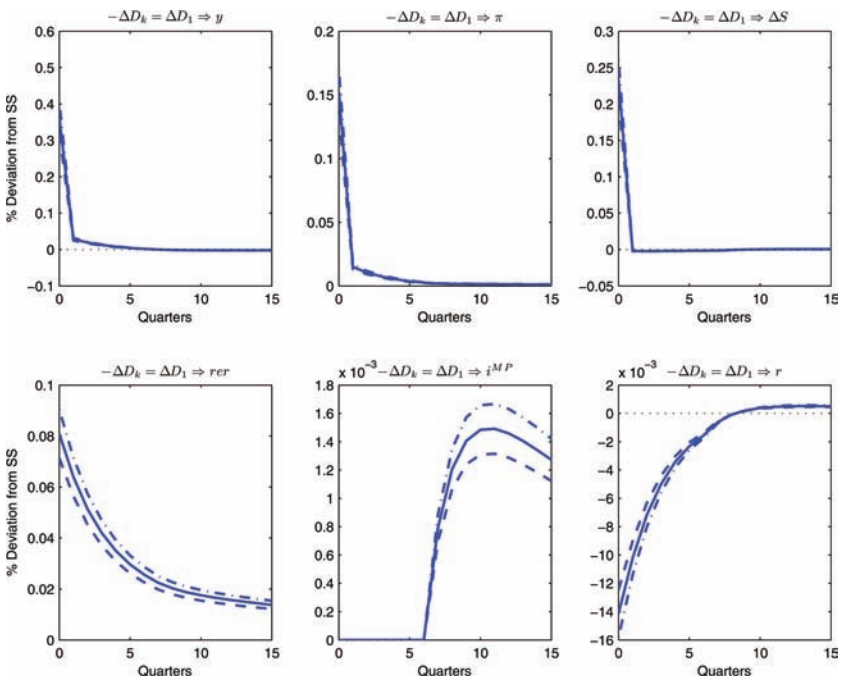
Note: The solid line shows the case when the policy rate is allowed to be negative, the dashed-dotted line considers a truncated Taylor rule, and the dashed line is the case of a truncated Taylor rule coupled with a purchase of long debt financed with new short debt equivalent to 50 percent of the steady-state nominal GDP.

Figure 20. Purchase of Foreign Assets Financed with a Monetary Expansion: $T = 6$, $p_t = 0$, Robustness with Respect to φ_m



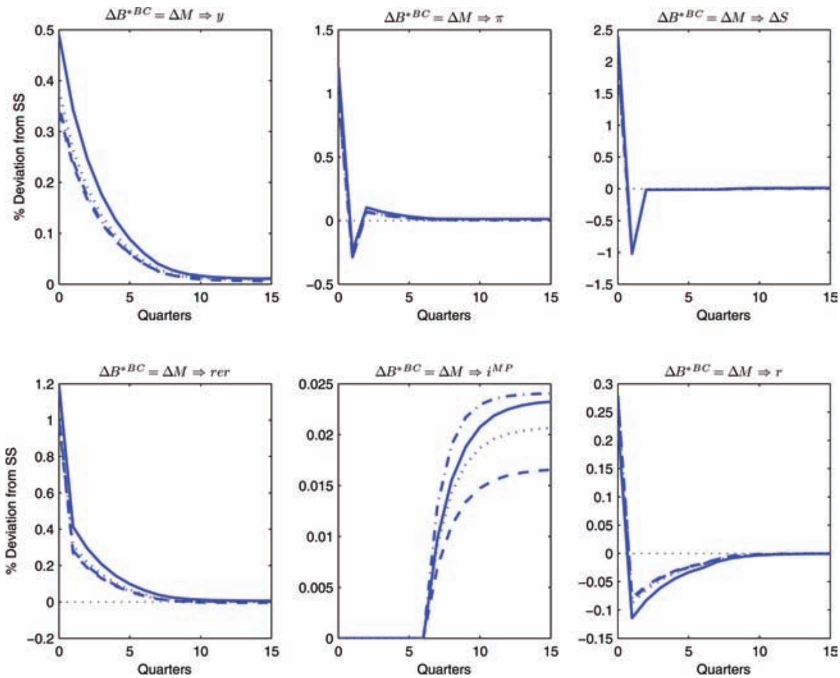
Note: The solid line corresponds to the benchmark case ($\varphi_m = -0.0014$), while the dashed-dotted and dashed lines are the cases with $\varphi_m = -0.0021$ and $\varphi_m = -0.0007$, respectively. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 21. Purchase of Long Debt Financed with New Short Debt: $T = 6$, $p_t = 0$, Robustness with Respect to φ_k



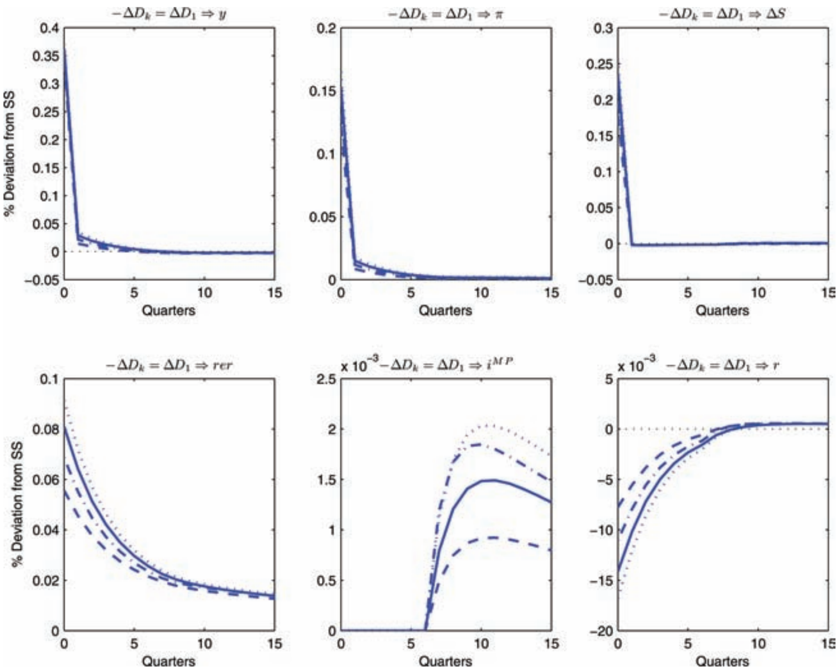
Note: The solid line corresponds to the benchmark case ($\varphi_k = 0.017$), while the dashed-dotted and dashed lines are the cases with $\varphi_m = 0.019$ and $\varphi_m = 0.015$, respectively. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 22. Purchase of Foreign Assets Financed with a Monetary Expansion: $T = 6$, $p_t = 0$, Robustness with Respect to the Taylor Rule



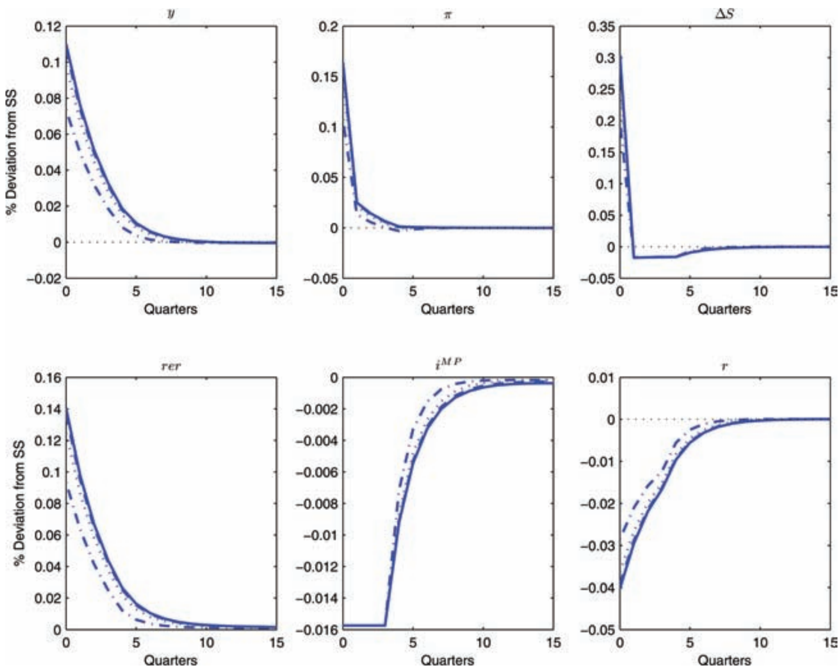
Note: The solid line corresponds to the benchmark case ($\rho_i = 0.74$, $\alpha_\pi = 1.67$, and $\alpha_\pi = 0.39$), while the dashed-dotted, dashed, and dotted lines are the cases with $\rho_i = 0.37$, $\alpha_\pi = 3.39$, and $\alpha_\pi = 0.78$, respectively. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 23. Purchase of Long Debt Financed with New Short Debt: $T = 6$, $p_t = 0$, Robustness with Respect to the Taylor Rule



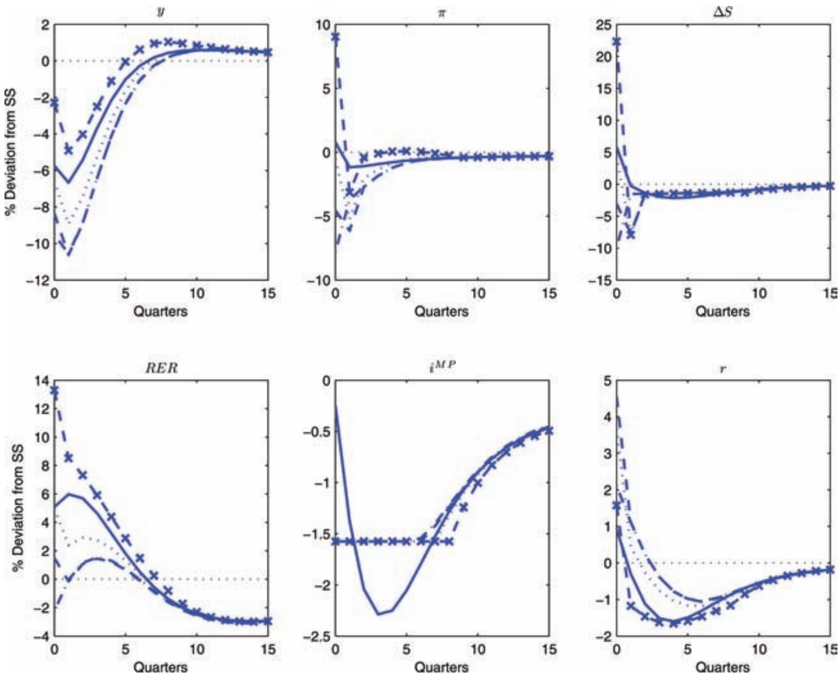
Note: The solid line corresponds to the benchmark case ($\rho_i = 0.74$, $\alpha_\pi = 1.67$, and $\alpha_\pi = 0.39$), while the dashed-dotted, dashed, and dotted lines are the cases with $\rho_i = 0.37$, $\alpha_\pi = 3.39$, and $\alpha_\pi = 0.78$, respectively. The shock is a permanent increase in B_t^{*CB} equivalent to 10 percent of nominal GDP in steady state, while i_t^{MP} remains in its steady-state value until T.

Figure 24. Driving i_t^{mp} to Zero: $T = 3$, $p_t = 0$. Robustness with Respect to the Taylor Rule



Note: The solid line corresponds to the benchmark case ($\rho_i = 0.74$, $\alpha_\pi = 1.67$, and $\alpha_\pi = 0.39$), while the dashed-dotted, dashed, and dotted lines are the cases with $\rho_i = 0.37$, $\alpha_\pi = 3.39$, and $\alpha_\pi = 0.78$, respectively. The experiment is to drive i_t^{MP} to zero and to keep it at this value until $T = 3$, with $p_t = 0$.

Figure 25. The Effects of a Contractionary Shock and Departures from the Taylor Rule in a Model with Habits



Note: The solid line shows the case when the policy rate is allowed to be negative; the dashed-dotted line considers a truncated Taylor rule; and the dashed, the dotted, and the crossed lines are the cases when i_t^{MP} is driven to zero and maintained at this value for, respectively, five, six, and seven quarters.

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Discussion of "On the Quantitative Effects of Unconventional Monetary Policies in Small Open Economies"*

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This paper contributes to the expanding literature on unconventional monetary policies. So far, much of the literature has focused on advanced economies. This may be natural because the United States and the European Union are the sources of the current crisis. However, many emerging markets have also been affected by the current crisis, and their central banks have employed unconventional policies. The paper is one of the earliest papers that consider unconventional monetary policies for an emerging economy.

García-Cicco modified the standard small open New Keynesian model by incorporating several frictions that motivate unconventional monetary policy. Those are as follows: the liquidity premium between the money market rate and short-term government bonds, the deviation from uncovered interest rate parity (UIP), and the term premium of long-term government bonds. The deviation from UIP may arise from costly adjustment of international portfolio. The term premium may arise from imperfect substitutability between long- and short-term bonds. It is assumed that policy instruments affect those friction terms directly. An increase in base money decreases the liquidity premium, the provision of foreign reserve affects the UIP condition, and the relative supply of long and short bonds affects the term premium. Even though those are assumed without microfoundations, it seems that those assumptions are reasonable. Financial frictions are estimated using Chilean data, and the estimated coefficients are interpreted as representing policy multipliers.

The paper considers four policy instruments: the money market rate, base money, supply of long and short bonds, and foreign

 The views expressed here are mine and do not necessarily reflect the official position of the Bank of Japan.

reserves. And four types of unconventional monetary policy are considered: purchase of foreign assets by selling money, purchase of domestic bonds by selling money, purchase of long-term bonds by selling short-term bonds, and purchase of foreign assets by selling bonds. The first two are thought to be liquidity provision because supply of money stock increases. The third and fourth change the composition of the central bank balance sheet while keeping its size.

When evaluating those policies, García-Cicco also takes into account the effects of expectations about the future course of policy rate. In the benchmark case, the money market rate is fixed forever. This is similar to the zero interest rate policy. In an extension, he considers the case in which the money market rate is temporarily fixed but afterwards is chosen by a Taylor-type policy rule. In addition to this, he assumes that the date of exit from the fixed interest rate policy is uncertain to private agents. This corresponds to the situation where commitment to the zero interest rate policy is not credible. When he analyzes exit from unconventional monetary policy, he considers anticipated exit as well as unanticipated exit.

The main finding is that the policies that provide liquidity have big effects, while the size of the effects depends crucially on expectations about the future course of the monetary policy rate. On the other hand, credit-easing policies that affect term premiums have smaller effects, but the size depends less on expectations. Finally it is shown that exit policy is contractionary.

García-Cicco makes an early and important contribution to the analysis of unconventional monetary policy for emerging markets. Future work would benefit from considering more explicitly the difference between types of unconventional monetary policy adopted in advanced economies and those in emerging markets. The difference may reflect differences in economic structure, types of shocks, and institutional characteristics. Ishi, Stone, and Yehoue (2009) collect episodes of unconventional monetary policy from thirty-five emerging markets. According to them, those emerging markets adopted unconventional monetary policies under much higher nominal interest rates, in contrast to advanced economies where the nominal rates virtually hit the zero bound. The average nominal rates in emerging markets are 5–9 percent, reflecting both high economic growth rates and high inflation. This implies that the zero lower bound is not a practical concern for many of those countries. Second, liquidity provision is widely used. This includes both provision of domestic liquidity and provision of foreign exchange. Twenty-eight countries injected domestic liquidity and twenty countries injected international liquidity. Chile injected both domestic and international liquidity. On the other hand, credit easing and quantitative easing have not been implemented.

Given those facts, the analysis of provision of international liquidity as well as domestic liquidity would be an interesting research topic. The current paper did consider the effects of purchase of foreign assets by selling bonds and shows that its effects are not very large. This policy is similar to the reverse of foreign exchange provision. However, since the demand for international liquidity is not explicitly modeled, the result of the paper may not be informative about the effect of foreign liquidity provision in practice.

Next, the types of unconventional monetary policies employed by emerging markets may depend on their economic structures. An important characteristic of emerging markets may be their dependence on foreign borrowing and risks of sudden stops. Dependence on foreign borrowing implies that those countries may not be able to lower the interest rates because low interest rates may put the countries at risk for capital outflow. The zero interest rate policy or quantitative easing are not options to them. Also, those countries tend to have less-developed domestic financial markets. Markets for securities and corporate bonds are much smaller. Then there may be no scope for credit easing.

The paper considers the credibility issue regarding commitment to a fixed interest rate. In general, commitment to a zero interest rate is time inconsistent. Therefore, the credibility issue analyzed in the paper is of practical concern. However, I think there is another credibility problem that is more relevant to emerging markets. Several emerging markets have less credibility regarding the long-run level of inflation. This can limit the types of unconventional policies they can use. This is because, compared with the traditional interest rate policy, unconventional monetary policies are less transparent and more discretionary. When the central bank has less credibility regarding the long-run inflation target and conducts quantitative easing, private agents might regard it as a sign of monetization, destabilizing inflation expectations.

Let me turn to some details of modeling. The model introduces three reduced-form frictions and estimates them. Quantitative evaluation is always welcome, but a question here is whether the estimated frictions really represent policy multipliers. First, the estimation period is from 2003 to 2009, which includes the period where unconventional monetary policies were not used. Then it is not very clear whether the estimated parameters really represent the effects of policy. Second, the Lucas critique says that policy evaluation based on a reduced-form model is problematic when expectations play a key role. This becomes particularly relevant when one analyzes credibility and anticipated vs. unanticipated policy.

Finally, it would be very important to identify the motivation behind the use of unconventional monetary policy. It can be a response to market malfunction. Examples include the Federal Reserve Board's purchase of mortgage-backed securities and the European Central Bank's purchase of government bonds. If this is the case, market malfunction should be explicitly modeled. It can also be an alternative to the interest rate policy after it hits the zero bound. An example would be quantitative easing. For emerging markets, since most countries used liquidity provision, their unconventional monetary policy may be justified as the responses to market malfunctions caused by foreign shocks. Relating to this point, let me finally comment on the results regarding the exit policy. It is shown that the exit policy is contractionary. However, I believe that this depends on whether a policy is a response to market malfunction or not. If the policy is a response to market malfunction and its effectiveness depends on the malfunctioning, then exit is not necessarily costly if markets recover their functions. On the other hand, if the policy is used as an alternative to the interest rate channel, then the exit policy may well be costly. In order to analyze this further, we need a microfounded model.

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Remarks on Unconventional Monetary Policy*

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To be useful in discussions about the rationale and effectiveness of unconventional monetary policy, models of monetary economies need to be modified. Progress on this is well under way and I review one approach here.

JEL Codes: E42, E58.

1. Introduction

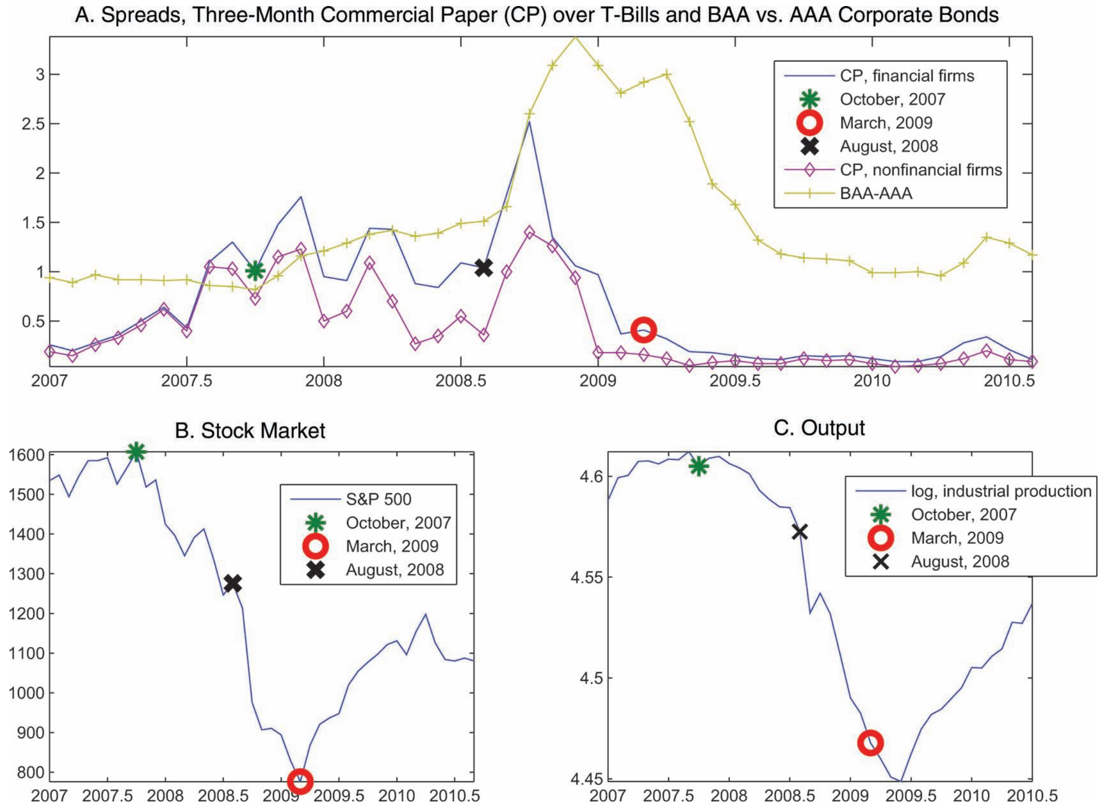
Figure 1 displays the facts that motivate this discussion. Interest rate spreads increased somewhat at the start of the 2007 recession and then widened substantially after August 2008. The Federal Reserve initiated a program of unconventional monetary policy in the fall of 2007, by purchasing privately issued assets and by permitting banks to use privately issued assets as collateral at the discount window. The Federal Reserve's program of unconventional monetary policy accelerated considerably in March 2009. At roughly the same time, interest rate spreads—initially the commercial paper spreads and then corporate spreads—returned to normal. Moreover, asset prices and economic activity began to bounce back from their plunge since late 2007 (see figures 1B and C). These observations raise the following questions:

- What are the economic mechanisms whereby unconventional monetary policy has its impact on interest rate spreads and economic activity?
- What are the market failures that unconventional monetary policy is designed to correct?

There is a wide range of actions that a central bank can take as part of an unconventional monetary policy. For example, it can make

*The author is grateful to Tao Zha for discussions.

Figure 1. Interest Rate Spreads, Stock Market, and Output



loans to banks, inject equity into banks, or purchase various kinds of asset-backed securities. Answers to the above questions determine which of these actions is desired and at what scale.

To address the above questions requires structural models of the economy that capture the linkages between interest rate spreads and the real economy. Several classic papers laid the groundwork for this long ago. This is why it is that even though little time has elapsed since the start of the recent turmoil, there is now a large number of models in place that can be used to study unconventional monetary policy.[1]

Broadly, there are three approaches to financial frictions. They can be organized around the question, "why are there interest rate spreads?" One answer has to do with liquidity: an asset that is hard to sell quickly in case the holder suddenly needs cash must pay a high return if it is to be held. If everyone comes to think that everyone else is unwilling to part with cash in exchange for financial assets, then there will be a general reluctance to purchase private assets and the liquidity premium on these assets will be high. These considerations were undoubtedly an important factor behind the rise in spreads in 2008, and it may justify the Federal Reserve's purchase of private assets at the time.[2] Another factor underlying interest rate spreads is the possibility of non-payment on risky loans. The approach taken in the work of Bernanke, Gertler, and Gilchrist (1999) and Carlstrom and Fuerst (1997) stresses observed costs associated with default.[3] However, recent work suggests that the very sharp increases in spreads in 2008 were too big to be accounted for by observed bankruptcies.[4] In part, this may be due to increased liquidity spreads. However, the moral hazard approach to interest rate spreads suggests another possibility—that spreads reflected a

[1]See, for example, Christiano, Motto, and Rostagno (2010), Cúrdia and Woodford (2009), Dib (2010), Gertler and Kiyotaki (2010), Hirakata, Sudo, and Ueda (2009a, 2009b, 2010), Meh and Moran (2010), Ueda (2009), and Zeng (2010).

[2]See, e.g., Moore (2009).

[3]The Bernanke, Gertler, Gilchrist (1999) approach has been used to study the financial factors driving recent business cycles as well as in the U.S. Great Depression (see Christiano, Motto, and Rostagno 2003, 2010). The approach has been extended to the analysis of risks in the banking system by Dib (2010), Hirakata, Sudo, and Ueda (2009a, 2009b, 2010), Ueda (2009), and Zeng (2010).

[4]See Gilchrist, Yankov, and Zakrajšek (2009).

fear of out-of-equilibrium default.[5] In my discussion I present a simple two-period example of this possibility, based on the paper by Gertler and Kiyotaki (2010).[6]

2. Model Analysis

The basic idea in the model is that the people who operate the intermediation industry come into contact with large sums of money, presenting them with opportunities to "steal." Stealing need not only mean that bankers literally abscond with money. There are other ways that the same thing can be accomplished. For example, bankers might not make a large effort to manage funds properly (i.e., they "steal" leisure) or they might make investments which do not earn a high return for depositors but do generate benefits for the bankers themselves. Under these circumstances, depositors are understandably reluctant to make deposits in banks. They do so anyway if they believe that bankers have committed their own funds to the industry in a way that if bankers misbehave, the bankers' own funds are put at risk.[7] The idea is that with their own "skin in the game," bankers have an incentive to behave properly. The funds committed by bankers correspond to their net worth. One could imagine that in normal times the net worth of the banking system is sufficient, so that depositors have little concern about mismanagement. However, if the net worth of banks suddenly undergoes a substantial drop (as in 2008), then there may not be enough net worth in the banking system for depositors to feel comfortable about committing their funds. In this case, the banking system functions at a lower rate and fewer projects are funded. To avoid passing up good projects, unconventional monetary policy—a policy in which the central bank takes over part of the intermediation industry—may be desirable and increase welfare.

We now turn to the formal two-period model. There are many identical households, each with a unit measure of members. Some

[5] Recent work on this includes Gertler and Karadi (2009), Gertler and Kiyotaki (2010), and Meh and Moran (2010).

[6] The example is based on ongoing work with Tao Zha. Other examples are reviewed in Christiano and Ikeda (2010).

[7] For an example of this idea, see Holmstrom and Tirole (1997).

Table 1. Problem of the Household

	Period 1	**Period 2**
Budget Constraint	$c + d \leq y$	$C \leq R^d d + \pi$
Problem: $\max_{c,C,d}[u(c) + \beta u(C)]$		

Table 2. Solution to Household Problem

$\frac{u'(c)}{\beta u'(C)} = R^d$	$c + \frac{C}{R^d} = y + \frac{\pi}{R^d}$
$u(c) = \frac{c^{1-\gamma}}{1-\gamma}$	$c = \frac{y+\frac{\pi}{R^d}}{1+\frac{(\beta R^d)^{\frac{1}{\gamma}}}{R^d}}.$

members are "bankers" and others are "workers." There is perfect insurance inside households, so that all household members consume the same amount, c, in period 1 and C in period 2. In period 1, workers are endowed with y goods and the representative household makes a deposit, d, in a bank subject to its period 1 budget constraint (see table 1).

Bankers in period 1 are endowed with N goods. They take deposits and purchase securities, s, from firms. Firms issue securities in order to finance the capital they use to produce consumption goods in period 2. Intermediation is crucial in this economy. Without it, production cannot occur, and period 2 production is the only source of the period 2 consumption goods. In period 2, households receive earnings, $R^d d$, on their bank deposits and profits, π, from bankers. The household chooses c, C, and d to maximize utility subject to the periods 1 and 2 budget constraints (see table 1).

Assuming a constant elasticity period utility function, the solution to the household problem is given in table 2.

We assume that $0 < \gamma < 1$, so that c is decreasing in R^d and d is increasing in R^d. The single intertemporal budget constraint in the model is derived by substituting out for d in the two-period budget constraints and imposing that maximizing households will choose a consumption bundle on the boundary of their budget constraint. According to the intertemporal budget constraint, the present discounted value of consumption must equal the present discounted

Table 3. Problem of the Bank in the Efficient Benchmark Model

Period 1	Period 2
Take Deposits, d	Pay dR^d to Households
Buy Securities, $s = N + d$	Receive sR^k from Firms
Problem: $\pi = \max_d[sR^k - R^d d]$	

value of income. As an aside, the expression highlights the fact that there must be frictions if the purchase of private assets by the government is to have an effect. For example, suppose the government raises lump-sum taxes, T, and uses the proceeds to purchase T securities from firms. Suppose that the government rebates the proceeds of this asset purchase in the second period to households in lump-sum form and that the government earns R^d on the private assets. Then, the household's intertemporal budget constraint is

$$c + \frac{C}{R^d} = y - T + \frac{\pi + R^d T}{R^d}.$$

Note that T cancels in this expression, so that it has no impact on the household's intertemporal consumption opportunities. As a result, the household's decisions about c and C are unaffected by T. Unless the government's purchase of private assets corrects some sort of private market failure, it will induce an equal reduction in private purchases and thus have no effect.

In practice, government intervention has costs that are not included in our model analysis. For example, it is generally understood that if the Federal Reserve purchases too many private assets, at some point it poses a risk to its independence. Central bank independence is crucial if it is to succeed in its mission of price stability. Thus, a policy that has no effect in the model could be very damaging if applied in practice.

We now turn to the banks in our model. We first consider the benchmark case in which there are no financial frictions (see table 3). We suppose that the gross rate of return on privately issued securities is technologically fixed at R^k. Bankers combine their own net worth, N, with the deposits received, d, to purchase securities, s,

Table 4. Definition of Equilibrium

Interior Equilibrium: R^d, c, C, d, π
Such that:
(i) The bank, household, and firm problems are solved.
(ii) Markets for goods and deposits clear.
(iii) $c, C, d > 0$.

from firms. Firms use the proceeds from selling these securities to purchase an equal quantity of goods which they turn into capital. The quantity of goods produced by firms in period 2 is sR^k. Goods-producing firms make no profits, so sR^k is the revenue they pass back to the banks. Banks pay dR^d on household deposits in period 2.

An equilibrium for the efficient benchmark version of the model is defined in table 4. A property of equilibrium is that $R^d = R^k$. To see this, suppose it were not so. If $R^d > R^k$, the bank would set $d = 0$ and if $R^d < R^k$, the bank would set $d = \infty$, neither of which is consistent with the interior equilibria that we study. Thus, in the efficient benchmark the interest rate faced by households coincides with the actual rate of return on capital. It is therefore not surprising that the first best allocations are achieved in this version of the model. That is, the allocations in the efficient benchmark equilibrium coincide with the allocations that solve the following planning problem:[8]

$$\max_{c,C,k} u(c) + \beta u(C)$$

$$\text{subject to} \quad c + k \leq y + N, \; C \leq kR^k.$$

In this economy there is no interest rate spread. This makes sense, since there are no costs associated with intermediation and there is no default.

Now consider the case of financial frictions. The bank has two options. It can choose not to "default," in which case it simply does what it does in the benchmark version of the model. In this case, the bank earns profits

[8] We assume the environment is such that $c < y$.

$$\pi = R^k(N + d) - R^d d.$$

Alternatively, the bank can choose to default. In this case it takes a fraction, θ, of its assets and reneges on its commitment to repay depositors. A defaulting bank receives $\theta R^k(N+d)$ and its depositors receive the rest, $(1-\theta)R^k(N+d)$. The bank chooses the no-default option if, and only if,

$$(N + d)R^k - R^d d \geq \theta(N + d)R^k. \tag{1}$$

Default will never be observed in equilibrium because households would not place deposits with a bank that has an incentive to default.

When the bank's incentive constraint, (1), is non-binding, then $R^k = R^d$ and the no-default condition reduces to

$$NR^k \geq \theta(N + d)R^k.$$

In an economy in which N is large, the above constraint is likely to be satisfied. However, if N is very small (consider, for example, the case $N = 0$), then the condition would fail. In this case, the equilibrium would not be characterized by $R^k = R^d$. Instead, $R^d < R^k$, so that d would be low. Both the high spread, $R^k - R^d$, and the low value of deposits, d, would help ensure that (1) is satisfied.

A sequentially repeated version of this model economy provides a very rough characterization of events before and after 2007. Suppose that N was large in the early period, so that the economy was operating at its efficient level and no part of actual spreads was due to the type of default considerations addressed here. Then, in late 2007 the net worth of banks suddenly began to fall. Spreads opened up, reflecting fears of default. The level of intermediation dropped and economic activity slowed down. The government responded by using tax dollars to make loans directly to firms. This caused spreads to narrow and the economy to begin to expand again.

3. Conclusion

Central bank intervention in private asset markets is potentially very costly. In the case of the United States, such interventions have the potential to put the central bank's independence at risk. This kind of risk should only be taken if the gains are correspondingly large.

Assessing the gains requires models. Such models allow one to decide if intervention is warranted and, if so, what sort of intervention. Fortunately, there is a range of models under development, each focusing on a different set of factors driving interest rate spreads. As an illustration, I briefly sketched a very simple model in these remarks. This model has been incorporated into a full-blown dynamic stochastic equilibrium model usable for policy analysis by Gertler and Kiyotaki (2010).

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Did Easy Money in the Dollar Bloc Fuel the Oil Price Run-Up?*

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Among the various explanations for the run-up in oil prices that occurred through mid-2008, one story focuses on the role of monetary policy in the United States and in developing economies. In this view, developing countries that peg their currencies to the dollar were forced to ease their monetary policies in response to reductions in U.S. interest rates, leading to economic overheating and higher oil prices. We assess that hypothesis using simulations of SIGMA, a multi-country DSGE model. Even when the currencies of many developing countries are pegged to the dollar rigidly, an easing of U.S. monetary policy leads to only a transitory run-up in oil prices. Instead, strong economic growth in many developing economies, as well as shortfalls in oil production, better explain the sustained run-up in oil prices observed between 2004 and 2008.

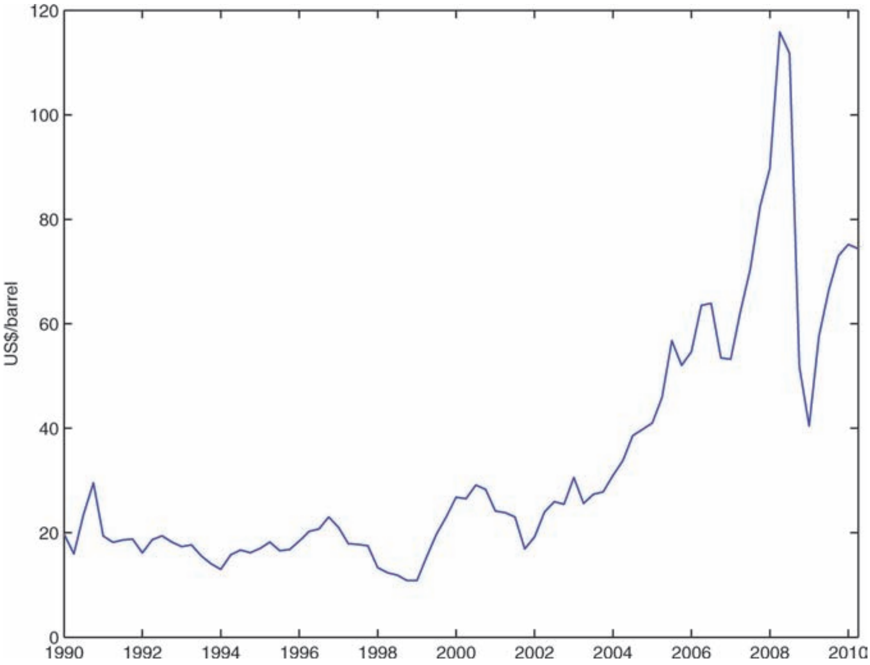
JEL Codes: F41, F42.

1. Introduction

During the years preceding the world recession, the price of oil shot up dramatically. As shown in figure 1, crude oil prices more than tripled between the end of 2002 and the end of 2007, and then rose another 60 percent or so to their peak in early July 2008. Given

 We are grateful to Martin Bodenstein, Giancarlo Corsetti, and Carl Walsh for helpful comments. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System. The authors are economists in the International Finance Division of the Federal Reserve Board. They can be reached at Christopher.Erceg@frb.gov, Luca.Guerrieri@frb.gov, and steven.kamin@frb.gov.

Figure 1. The Price of Oil (U.S. Refiners' Acquisition Cost for Imported Crude)



the consequences of these movements for global inflation, economic activity, and the pattern of external imbalances, it is not surprising that they garnered tremendous attention from analysts and policymakers alike. More recently, the global spotlight has shifted away from the price of oil, partly because it has come down considerably since its peak and also because of the subsequent financial crisis and recession around the world.

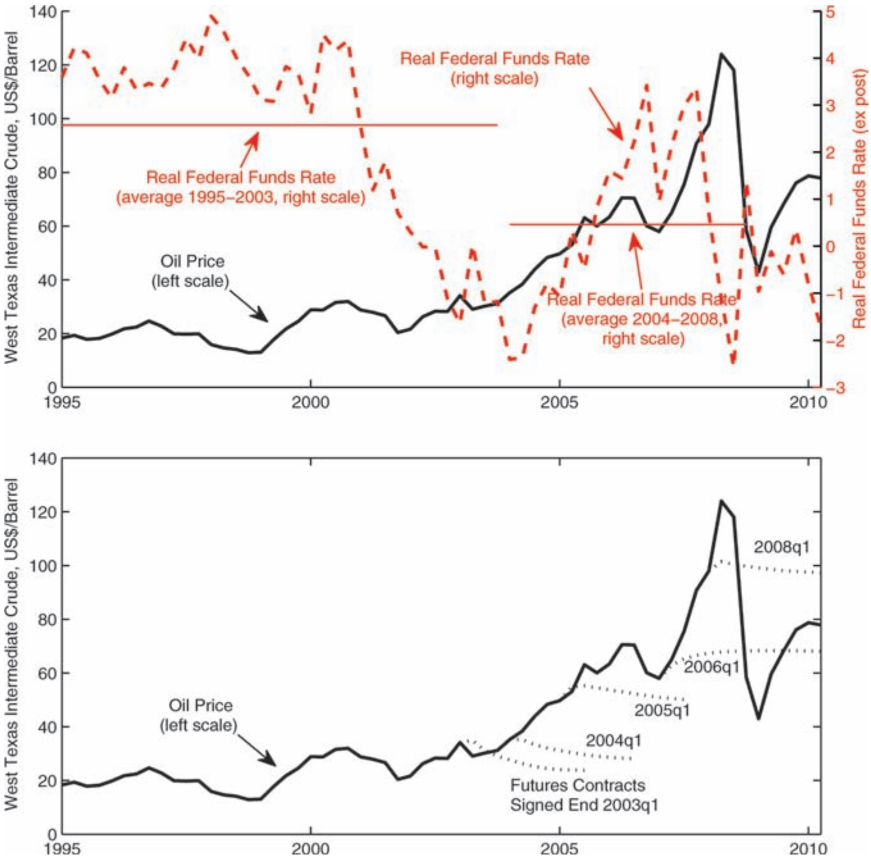
Yet, the behavior of oil prices remains an important issue for the global economy. First, the price of oil remains quite elevated relative to its level earlier in this decade. Second, its prior run-up exacerbated the effects of the financial turmoil: it reduced real disposable income in many commodity-importing countries, and its inflationary effects constrained some central banks from loosening monetary policy in response to financial strains. Finally, as global economic conditions improved, the price of oil has moved up from its recent lows, raising the question of where it will stabilize.

Accordingly, understanding the run-up in the price of oil prior to the global recession remains a high priority for analysts and policymakers. A plethora of explanations for the rise, many of them complementary, have been advanced. One group of these focuses on the fundamentals of supply and demand: industrialization in China and other developing countries substantially boosted the demand for oil, while a combination of slowly growing capacity, weather problems, and geopolitical concerns prevented the supply from keeping up. A second explanation focuses on the role of speculators in driving up commodity prices in general. According to a third explanation—advanced by Frankel (2008)—declines in interest rates caused by the Federal Reserve's monetary easing led to a run-up in the price of oil by depressing the dollar and by reducing the cost of holding inventories, thus diminishing the incentive to extract resources today rather than saving them for the future.

Finally, in the last couple of years, a fourth broad explanation for the run-up in the price of oil emerged which, intriguingly, married elements of the fundamentals-based explanation with the view that the run-up was caused by Federal Reserve loosening. This explanation, which for convenience we will call the "dollar bloc" story, starts with the premise that many developing economies have pegged their currencies to the U.S. dollar. When the Federal Reserve loosened monetary policies, these developing countries had to loosen their policies as well, even though such loosening was not appropriate to their economic circumstances. This led to an overheating of their economies, excess demand for commodities such as oil, and sharp increases in commodity prices. As shown in figure 2, U.S. real interest rates were lowered sharply during the 2001–02 recession and remained well below their historical average through the period between 2003 and mid-2006, and against this backdrop, oil prices rose markedly. The dollar bloc explanation was pithily summarized by Martin Wolf (2008):

> Today, the hapless Federal Reserve is trying to re-expand demand in a post-bubble U.S. economy. The principal impact of its monetary policy comes, however, via a weakening of the U.S. dollar and an expansion of those overheating economies linked to it. To simplify, Ben Bernanke is running the monetary policy of the People's Bank of China. But the policy appropriate to

Figure 2. U.S. Policy Rates and the Price of Oil



the U.S. is wildly inappropriate for China and indeed almost all the other countries tied together in the informal dollar zone or, as some economists call it, "Bretton Woods II."

Similarly, in 2008, an article in the *Economist* entitled "A Tale of Two Worlds" observed:

Apart from the Gulf States, few countries still peg their currencies to the dollar, but most try to limit the amount of appreciation. This means that as the Fed cuts rates there is pressure on emerging economies to do the same, to prevent capital inflows pushing up their exchange rates. In the face of rising

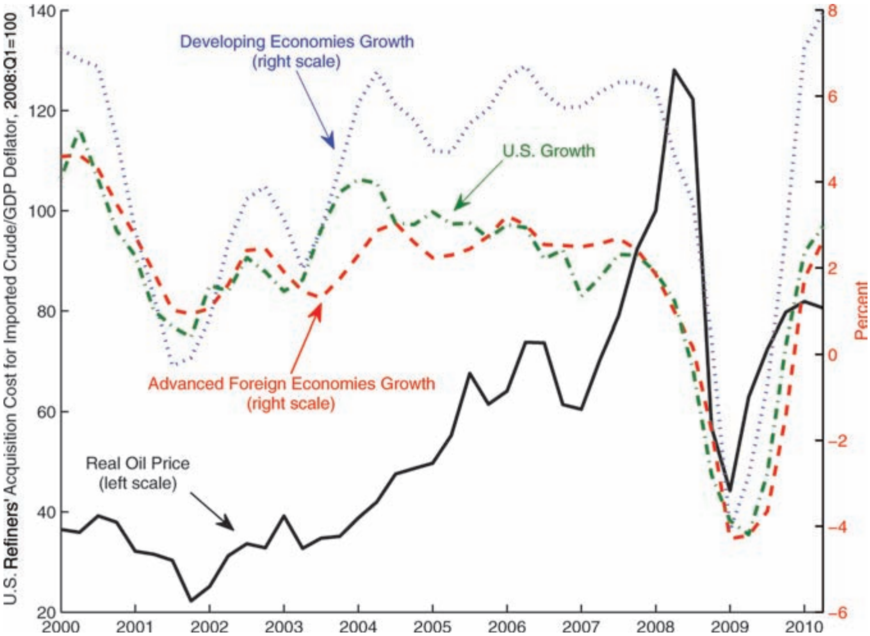
> inflation, emerging economies should be lifting interest rates, not cutting them, but their rigid currency policies makes this hard. In turn, continued surging demand in emerging economies boosts commodity prices, which reduces Americans' spending power and so encourages the Fed to cut rates further. The more the Fed cuts, the bigger the risk of inflation in emerging markets.

This paper assesses the plausibility of the dollar bloc explanation for the run-up in the price of oil using SIGMA, a forward-looking dynamic general equilibrium model comprised of three country blocks. Our model simulations indicate that, in a world where an appreciable portion of the global economy (20 percent) is assumed to be pegged to the dollar, a loosening of U.S. monetary policy on the order of what occurred in recent years—with the real federal funds rate falling some 2 percentage points below its historical average in 2004 through 2007—can indeed cause a sharp spike in oil prices. This occurs because the economies pegged to the dollar receive stimulus (both as their currencies follow the dollar downward and as they loosen their own monetary policies) and this boosts their GDP and thus their demand for oil. However, the spike in oil prices is short lived. As the pegged economies overheat, their GDPs return to trend, oil demand softens, and oil prices retrace their earlier rise.

The transient nature of the oil price hike implied by our model simulations seems at odds with historical experience. In particular, the dramatic oil price increases that occurred over 2004–08 have been highly persistent and appear to have been perceived as such by financial markets. As seen in the lower panel of figure 2, rising oil spot prices over that period—the solid line—were associated with a similar-sized shift in the oil futures path—the dotted lines. Thus, our model suggests that U.S. monetary policy easing is not a good candidate for explaining the large and durable run-up in oil prices that occurred between 2003 and 2008. As an important corollary, the channels through which U.S. monetary policy changes affect U.S. output and core inflation are not much affected by the presence of a dollar bloc.

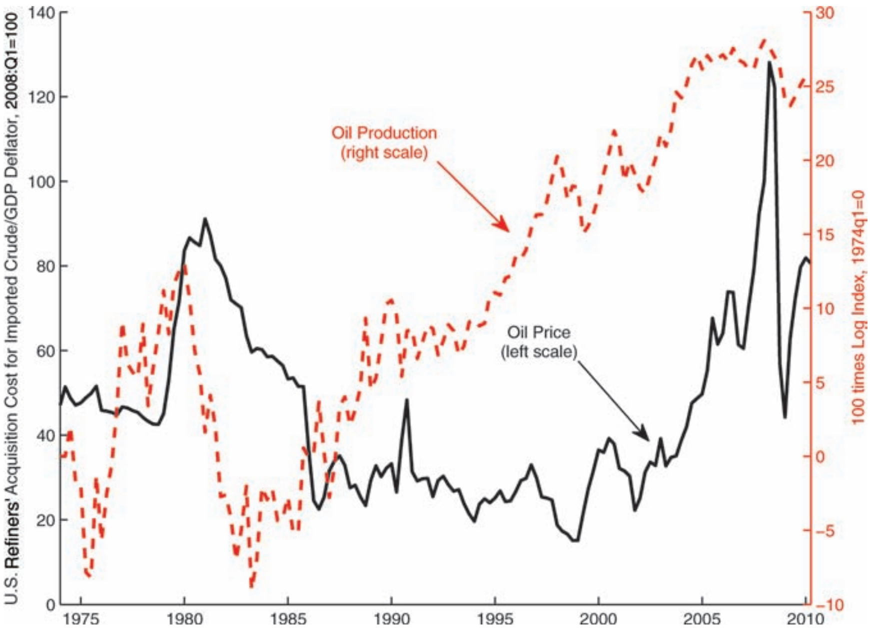
If U.S. monetary easing does not explain the run-up in oil prices, what does? We performed a number of simulations to assess the

Figure 3. Recent Global GDP Growth and Real Oil Prices



plausibility of the most prominent "fundamentals"-based explanations for the surge in oil prices. To begin with, we analyzed the effects of an acceleration of productivity growth sufficient to boost world GDP growth by about 1 percentage point; this increase is comparable to the run-up in global growth seen earlier this decade compared with its historical average (see figure 3). Our model simulation suggests that such an increase in economic growth, because it is sustained, could lead to a similarly sustained rise in oil prices in the neighborhood of 70 percent above their baseline level. We then evaluated the impact of a sustained reduction in the growth of global oil production of 1.5 percentage points, comparable to the reduction in oil supply growth that actually occurred in recent years (as seen in figure 4, global oil production has essentially stalled since 2004). Such a shock would boost the price of oil persistently more than 30 percent above its baseline level. Combining both simulation experiments, we find that the higher global GDP growth and the reduction in oil supply would together lead to a sustained doubling of the oil

Figure 4. World Oil Production and Real Oil Prices



price, roughly comparable to the increase in oil prices between 2004 and the fall of 2010.

In sum, the fundamentals-based explanation for the run-up in oil prices appears more plausible than the "dollar bloc" story, and this holds true even under the somewhat heroic assumption that a fifth of the global economy (including most developing economies) is rigidly pegged to the dollar.

2. Model Description

SIGMA is a multi-country, multi-sector dynamic general equilibrium model used for policy analysis by Federal Reserve staff. The model structure builds heavily on Erceg, Guerrieri, and Gust (2006) and Bodenstein, Erceg, and Guerrieri (2011). We conduct our simulations in a three-country version of the model that includes the United States, a group of "dollar bloc" countries that maintain fixed exchange rates against the U.S. dollar, and an aggregate "rest of the world" (ROW) bloc comprised of all other foreign countries.[1] Monetary policy in both the United States and the ROW bloc is assumed to follow a modified Taylor rule that reacts to inflation and output growth (rather than the output gap), and which allows for a modest degree of interest rate smoothing.

SIGMA has a high degree of formal similarity in the structure of key behavioral equations across the three country blocs. The core of the model has its antecedents in the seminal open-economy modeling framework of Obstfeld and Rogoff (1995), but it embeds a wide array of nominal and real rigidities that have been identified by the literature as important empirically. Thus, consumption behavior is consistent with the permanent income hypothesis in the longer term, though our model incorporates habit persistence, which effectively makes consumption more inertial in the short run. Investment depends on Tobin's Q, though we follow Christiano, Eichenbaum, and Evans (2005) in assuming that investment adjustment costs depend on the change in investment rather than in the capital stock. This increases the persistence in the investment response relative to the standard Q-theory approach. Government spending evolves exogenously (as a share of GDP), and the fiscal authority is assumed to adjust lump-sum taxes in a manner that enables the government to satisfy its intertemporal solvency constraint.

On the aggregate supply side, inflation is determined by a fairly conventional New Keynesian Phillips curve that allows for some intrinsic persistence: thus, inflation depends partly on its own lag but also on marginal cost and the inflation rate expected to prevail in the future. Marginal costs rise when output exceeds potential or when real wages rise above the level that would prevail if wages were completely flexible (in which case wages would immediately adjust to changes in fundamentals, such as higher oil prices). Nominal wages change sluggishly given that they are set in long-term staggered contracts. This contributes to some additional inertia in prices given the substantial influence of wages on marginal cost.

[1] A more complete description of the model and its calibration is provided in a technical appendix to this paper that is available on the Federal Reserve Board's web site as supplementary material to International Finance Discussion Paper No. 979.

Each country or country bloc in our model is regarded as producing a basket of non-oil goods that it can either export or use to satisfy domestic demand. Because each country's basket is an imperfect substitute with the basket produced by other countries, the demand curve for its export basket is downward sloping in its relative price. Producers in each country are assumed to set prices in the buyers' currency (following a Calvo-style timing assumption for price setting). This is consistent with the "local currency pricing" assumption embedded in many open-economy macro models (e.g., Betts and Devereux 1996) and implies gradual adjustment of trade prices to exchange rate movements. Moreover, our model incorporates adjustment costs that penalize rapid changes in bilateral trade shares. This specification captures the idea that it may be costly for households and firms to vary the composition of their import basket in the short run in response to relative price changes, even while allowing aggregate imports to respond rapidly to changes in real activity.

Our model also includes a world oil market in which the price of oil is determined to equate world demand and supply. In each country, oil is demanded by firms as an input into production and by households as a component of their consumption bundle (which also includes imports and domestically produced goods). In line with our specification of non-oil trade, our model incorporates adjustment costs that penalize rapid changes in the share of oil used in production and consumption. As a result, the short-run price elasticity of demand for oil is much lower than the long-run elasticity of demand, consistent both with empirical and anecdotal evidence. Oil supply is assumed to be exogenously fixed in each country bloc, though the initial endowment is much larger relative to per capita output in the ROW bloc; accordingly, the latter is a net exporter of oil, while the United States and the dollar bloc countries are importers.

Turning to the calibration, the relative population size parameters are chosen so that the United States comprises about 25 percent of world output. The dollar bloc is assumed to include most major developing economies in both developing Asia and Latin America (referred to as the DA-LA bloc below) and accounts for 20 percent of world GDP. Even though some countries that are admittedly dollar peggers are omitted from the dollar bloc due to data limitations—notably some Middle East oil exporters—this omission is more than counterbalanced by the inclusion of a broad set of major developing countries that allow their currencies to vary substantially against the dollar. Thus, we interpret the 20 percent share of world output as an upper bound on the importance of the dollar bloc. The ROW accounts for the remainder of world GDP (55 percent). We use national accounts data to calibrate expenditure shares for each of the three country blocs in our model. Model parameters determining bilateral trade flows for non-oil goods are derived using nominal trade shares from the International Monetary Fund's (IMF's) *Direction of Trade Statistics.*

Using 2007 data from the British Petroleum *Statistical Review*, we calibrate oil imports for the United States to 67 percent of total demand in the non-stochastic steady state, implying that 33 percent of oil demand is satisfied by domestic production. Similarly, for the dollar bloc, we calibrate oil imports to 40 percent of total oil demand. We use data on oil use from British Petroleum and the International Energy Agency (IEA) to calibrate the energy intensity of each country bloc. The share of energy in consumption is set to 1.9 percent for the United States, 3.7 percent for the DA-LA bloc, and 1.6 for the ROW; the share of energy in production is set to 2.7 percent for the United States, 4.4 percent for the DA-LA, and 3.4 for the ROW. Finally, the adjustment cost parameters on oil use in production and consumption imply a half life of the response of oil expenditure to a permanent oil price change of ten years.

3. Simulation Results

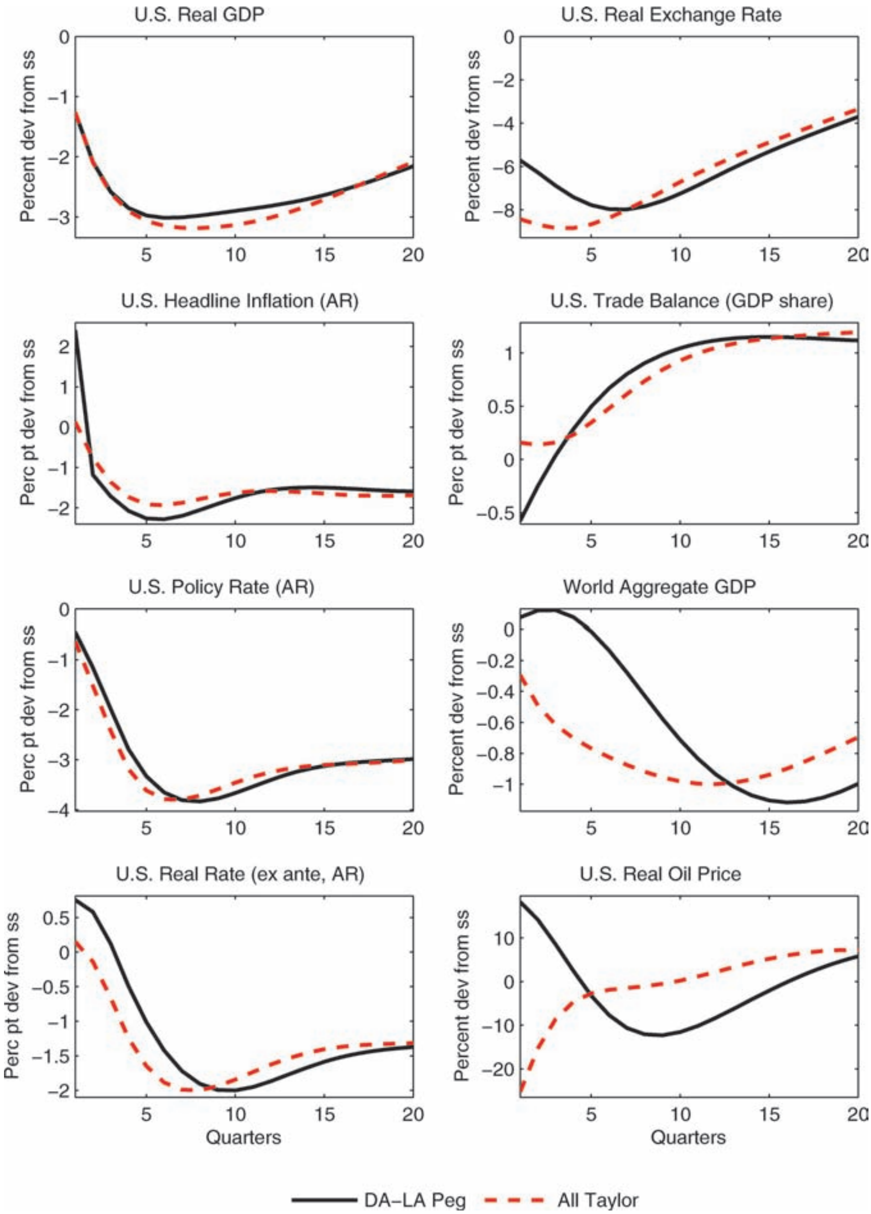
A key objective of our simulations is to evaluate the hypothesis that accommodative U.S. monetary policy in response to adverse shocks originating in the United States generated a boom in emerging market countries through the mechanism of fixed exchange rates, thus helping to fuel a run-up in oil prices. Of course, some have argued that during the 2000s, U.S. monetary policy loosened by more than was consistent with a systematic response to cyclical economic conditions, and it was this excessive loosening that led to undesirable outcomes (see Taylor 2000). Disentangling how much of the movement in the federal funds rate was attributable to the systematic component of the monetary policy rule and how much was due to monetary policy innovations is a complicated task. To simplify, we consider two extreme cases. In the first case, we attribute all of the observed fall in the U.S. real interest rate to the systematic component of policy: rates drop because a shock to U.S. consumption demand causes a large drop in U.S. activity. In the second case, all of the movement in the U.S. real rate is due to unforeseen monetary policy innovations. Given the model's linearity, the effects in intermediate cases may be viewed as a convex combination of these extremes.

3.1 U.S. Aggregate Demand Shock

We begin by analyzing the effects of a country-specific decline in the exogenous component of consumption demand in the United States. As seen in figure 5 (lower-left panel), the shock is scaled so that the U.S. real interest rate falls 2 percentage points below baseline, which is roughly the average amount by which the real federal funds rate over the 2004–08 period dipped below its corresponding average over the 1990–2003 period (recalling figure 2). The shock is assumed to follow an AR(1) process, with a persistence parameter of 0.975.

In order to assess the impact of monetary policy in the dollar bloc countries, we contrast our benchmark calibration in which the dollar bloc countries maintain pegged exchange rates ("DA-LA Peg") to an alternative in which all countries, including those in the dollar bloc, follow the Taylor rule ("All Taylor"). As seen in figure 5, the U.S. aggregate demand contraction has quite similar effects on output, inflation, and interest rates in the United States irrespective of the particular assumption about foreign monetary policy. U.S. output falls persistently, headline price inflation falls below baseline in response to the negative output gap (notwithstanding a transient initial rise due to higher oil prices), and U.S. policy rates decline as implied by the Taylor rule. Because U.S. real short-term interest rates fall much more sharply than interest rates abroad, the U.S. real exchange rate depreciates. This stimulates U.S. real net exports and helps cushion the impact of the domestic spending decline on U.S. GDP. As expected, the size of the real dollar depreciation is somewhat smaller in the benchmark case in which 20 percent of the world pegs than if all countries followed a Taylor rule. Although this implies that the stimulus to U.S. exports arising from a relative price channel is smaller in the benchmark case, foreign activity shows a

Figure 5. U.S. Aggregate Demand Shock



much larger expansion (as shown below). As a result, the stimulus to U.S. real exports turns out to be fairly similar irrespective of the assumption about monetary and exchange rate policy in the dollar bloc. This implication and the relatively low degree of openness of the U.S. economy help explain why U.S. output appears nearly invariant to the assumption about foreign monetary policy.

By contrast, the effects of the U.S. aggregate demand contraction on foreign economies depend starkly on the monetary and exchange rate policy pursued by the dollar bloc countries. Focusing initially on the case in which all countries follow the Taylor rule—the dashed lines—output and inflation in both the dollar bloc countries (shown in figure 6) and in the ROW (figure 7) are basically insulated from the effects of the U.S. shock. Although their real net exports decline due to exchange rate appreciation and the fall in U.S. activity, the contractionary effect on GDP is more than offset by higher domestic demand as monetary authorities abroad cut interest rates. Moreover, real exchange rate appreciation depresses the price of imported capital goods, which also boosts investment (in both the DA-LA and ROW economies).

The solid lines in figure 6 show the effects of the U.S. demand shock on the DA-LA bloc under our benchmark case in which 20 percent of the world economy consists of countries that peg to the dollar. Policy rates in the DA-LA bloc (lower-left panel of figure 6) decline in lockstep with U.S. nominal interest rates, exerting a highly expansionary effect on domestic absorption in the DA-LA bloc. The stimulus from lower policy rates is reinforced by a sharp depreciation of the DA-LA multi-lateral real exchange rate, which mainly reflects nominal depreciation against the ROW currencies. DA-LA real GDP rises substantially, with real exports expanding despite the fall in U.S. activity. As seen in figure 7, output in the ROW rises modestly, notwithstanding the contractionary impact of exchange rate appreciation on real net exports. The output expansion mainly reflects that investment rises as real exchange rate appreciation lowers the cost of capital goods.

Returning to figure 5, the different foreign output responses associated with alternative assumptions about monetary policy in the dollar bloc countries translate into a sizable disparity in the initial response of the oil price in our model. In the case in which all countries follow the Taylor rule, lower world output (mainly because of

Figure 6. U.S. Aggregate Demand Shock (Responses of DA-LA Bloc)

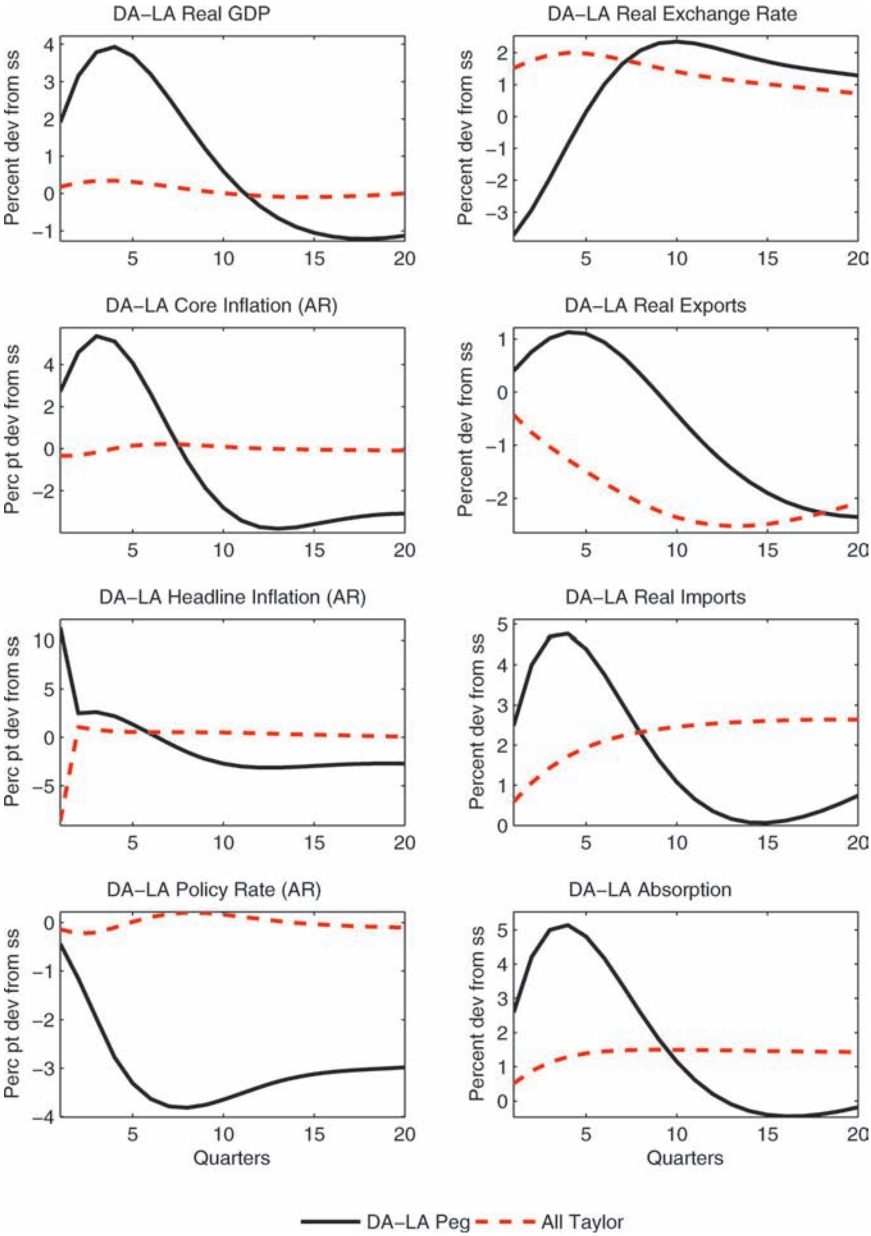
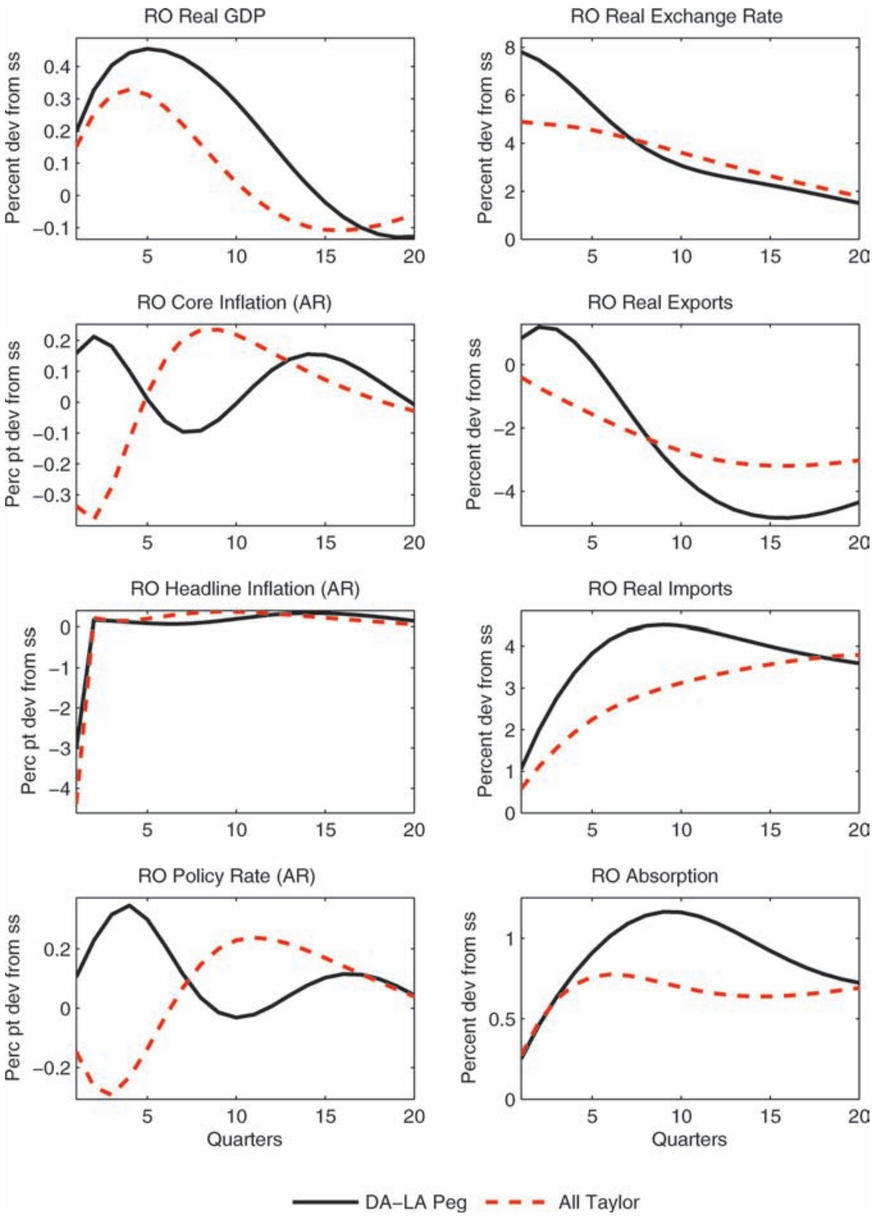


Figure 7. U.S. Aggregate Demand Shock (Responses of ROW Bloc)



the large contraction in the United States) causes the oil price to fall almost 25 percent below baseline in the impact period, and roughly 5 percent after one year. By contrast, the oil price rises by around 15 percent initially in the benchmark case in which dollar bloc countries peg. The disparity in the oil price responses in the face of fairly modest differences in the response of world GDP reflects that the oil price elasticity of demand is extremely low in the short run in our model, in the neighborhood of only 0.01 percent in the impact quarter of the shock (consistent with a half life of adjustment to a relative price change of ten years).

But even if pegged exchange rates in some trading partners induced an initial rise in oil prices by as much as suggested in our model simulation, a key implication of our model is that this channel cannot account for permanent or even persistent increases in the oil price in response to accommodative U.S. monetary policy. The oil price rise under our benchmark case is wholly attributable to a temporary (even if somewhat persistent) rise in foreign output gaps. After an initial spike, oil prices in the simulation rapidly decline toward the steady state. This evidently contrasts with the nature of the actual run-up in oil prices in the years before the global financial crisis.

The implications of these model simulations for agents' expectations about the future path of oil prices also appears inconsistent with historical experience. Agents in the model forecast that most of the oil price increase will be reversed within a couple of years. However, the oil price hikes that occurred over the 2003–08 period appear to have been perceived as largely permanent, recalling our discussion of the oil futures path in the lower panel of figure 2. This casts doubt on the hypothesis that a loosening of U.S. monetary policy in response to the weakening economy contributed markedly to the run-up in oil prices.

3.2 U.S. Monetary Policy Shocks

Figures 8 and 9 show the effects of an alternative cause of the loosening of U.S. policy—namely, a series of unforeseen i.i.d. monetary policy innovations that lowers the real interest rate (based on core inflation) by 2 percentage points over a four-year period. Thus, in contrast to the simulations above, all of the drop in the real policy rate in the 2004–08 period relative to the average over the 1990–2003

Figure 8. U.S. Monetary Policy Shock

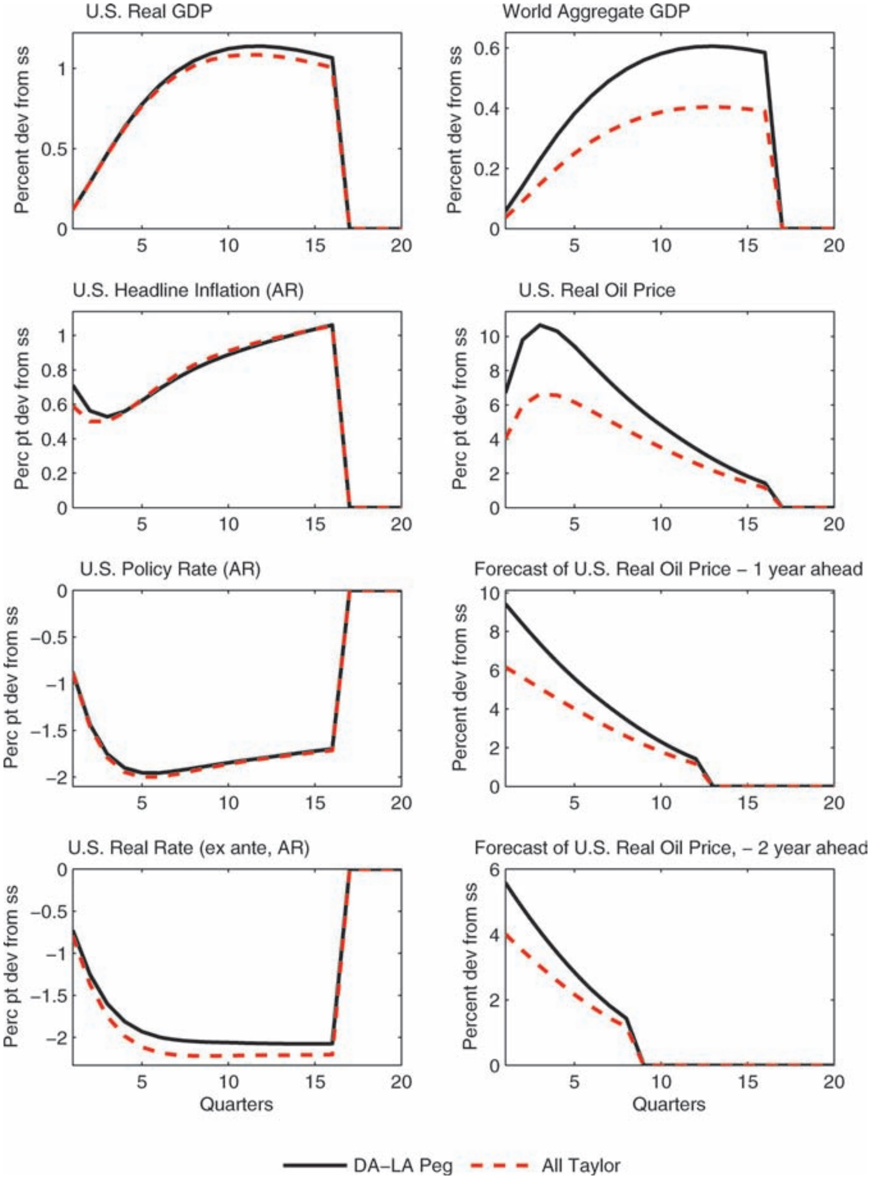
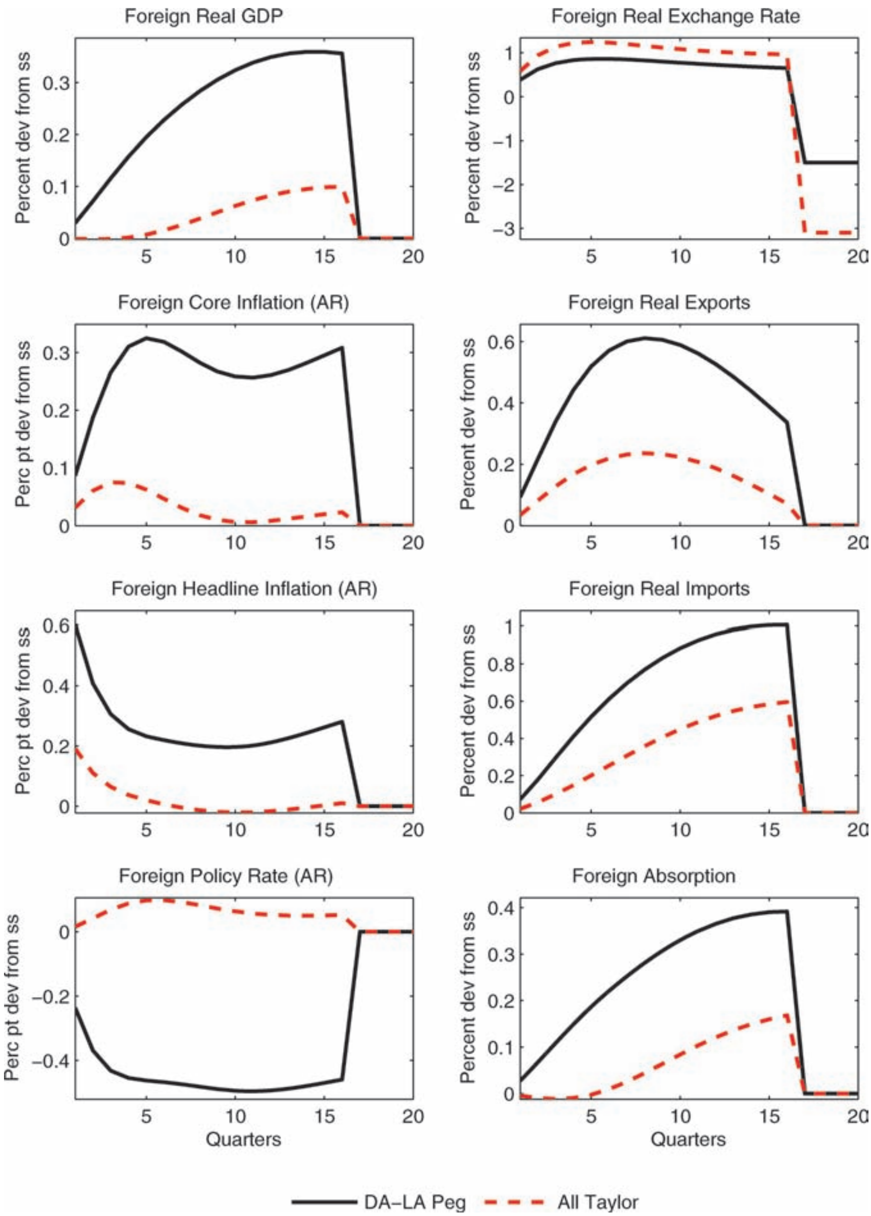


Figure 9. U.S. Monetary Policy Shock (Aggregate Foreign Responses)



period is attributed to the unsystematic component of the policy rule. The average fall in the nominal policy rate over the first four years of the simulation—of around 175 basis points—turns out to be very close to the upper range of "Taylor-rule deviations" reported by Dokko et al. (2009). In particular, Dokko et al. (2009) report an average deviation of around 200 basis points over 2003 to mid-2006 when the inflation measure in the Taylor rule is taken to be headline inflation, and when the output gap is based on the current vintage of revised data. However, those authors emphasize that the Taylor-rule deviations are much smaller and less persistent under alternative inflation measures, including core PCE inflation, and when the output-gap measure is based on real-time data. Accordingly, we interpret our results as indicating an upper range of the effects on output and inflation that might be associated with departures from a Taylor rule in our model.

As before, we contrast our benchmark calibration in which the dollar bloc countries maintain pegged exchange rates ("DA-LA Peg") to an alternative in which all countries, including those in the dollar bloc, follow the Taylor rule ("All Taylor"). U.S. GDP (figure 8) rises under either assumption about monetary policy abroad, as lower interest rates stimulate the interest-sensitive components of domestic spending, and as dollar depreciation boosts real net exports. Turning to figure 9, aggregate foreign output is nearly unaffected by the U.S. monetary policy shock under the "All Taylor" case, reflecting that the stimulus from higher U.S. activity is offset by exchange rate appreciation (n.b., the foreign variables in figure 9 are averages of the DA-LA and ROW responses computed using U.S. trade weights). By contrast, aggregate foreign output rises much more under the DA-LA peg, almost wholly due to a substantial expansion of DA-LA output as interest rates fall.

Returning to figure 8, world GDP rises under either assumption about foreign monetary policy, and given a fixed oil supply, oil prices must rise. However, given that the output boost is transient, the oil price rise also shows little persistence. Accordingly, even if monetary policy had been looser than needed to respond to economic conditions, our model results suggest that such loosening could not explain the sustained run-up in oil prices prior to the global recession.

Insofar as our model implies that oil price movements must be highly persistent to exert much effect on U.S. core inflation and output, the oil price hikes induced by the policy response abroad have relatively little impact on U.S. output and core inflation. Moreover, certain features of our simulations may exaggerate the actual short-term impact of monetary policy loosenings on oil prices (and hence headline inflation). First, some of the sizable quantitative effects shown in figures 5 and 8 simply reflect that the shock to the United States is both large in magnitude and occurs very rapidly: for example, U.S. GDP contracts a full 3 percent in a period of one year in response to the negative aggregate demand shock. With a more gradual phasing-in of the shock, the initial effects on oil prices would differ less across the alternative specifications of DA-LA monetary policy. Second, our model does not allow for oil inventories or variable capacity utilization. In the presence of these features, the perception that the oil price would fall in the future (due, say, to a winnowing of the foreign output gap) would create an incentive to sell inventories and boost current production. Thus, the initial rise in the oil price would be attenuated compared with that shown in figures 5 and 8. Finally, our calibration that imposes a ten-year half life of adjustment contributes to a much larger oil price rise after an increase in world GDP than suggested by some empirical estimates. In particular, while our calibration suggests that a 1 percent rise in world GDP would push up the real price of oil by over 50 percent on impact, this is roughly ten times as large as estimated by Kilian (2009) using a structural VAR framework to identify various shocks affecting oil prices.

To sum up, our model results indicate that even in the presence of a substantial dollar bloc abroad, a loosening in U.S. monetary policy can generate only a transient increase in global output and hence in oil prices, and this result obtains irrespective of whether the monetary loosening is in response to weakening activity or to the unsystematic component of policy. Accordingly, the channels through which U.S. monetary policy changes affect U.S. GDP and core inflation—and forecasts of headline inflation at a horizon beyond a year—are not materially affected by the presence of a dollar bloc. Moreover, although our model implies sizable movements in headline inflation in the short run, it probably overstates such fluctuations insofar as it abstracts from empirically realistic features that would allow greater intertemporal smoothing in oil production and oil demand.

Of course, it is possible that U.S. monetary loosening may impact oil prices in a more persistent manner than captured by our model. For instance, if the monetary shocks considered in figure 8 were more persistent, U.S. output would show a somewhat larger and persistent rise, and oil prices would be affected in a commensurate manner. A problem with this explanation, however, is that more persistent innovations tend to boost expected inflation at horizons beyond a year substantially; but in reality, inflation expectations (except at very short horizons) remained remarkably well anchored at around 2 percent throughout the 2003–06 period.

More plausibly, a potential limitation of our modeling framework is that agents are assumed to have perfect foresight about the underlying sources of all movements in real activity and inflation. In particular, in our simulations agents can immediately recognize that the source of the initially faster foreign GDP growth is accommodative U.S. monetary policy, and hence that any associated boom in oil prices must be transient. But to the extent that it is difficult in practice to disentangle shocks, it is plausible that a boom in fast-growing regions of the world—such as the DA-LA bloc—might be interpreted as driven exclusively by faster productivity growth, when in fact some of the boom was due to monetary stimulus. Accordingly, in a richer modeling environment that allowed for imperfect information about shocks, U.S. monetary policy could possibly exert somewhat larger and more persistent effects on oil prices than implied by our simulations.

3.3 Other Explanations for the Run-Up in Oil Prices

We now turn to using our model to consider the quantitative effects of other shocks that may have exerted a pronounced effect in driving up world oil prices during the past few years. It seems reasonable to focus attention on two particular explanations. First, it seems plausible that faster-than-expected growth in world output—especially in developing economies such as China and India—may have made an important contribution to driving up oil prices. Second, growth in world oil supply has slowed markedly, and projections for the future level of oil production have been revised downward dramatically since the early years of this decade.

Figures 10 and 11 report the effects of a SIGMA simulation in which foreign real GDP growth initially rises about 1.5

Figure 10. Foreign Technology Growth Shock

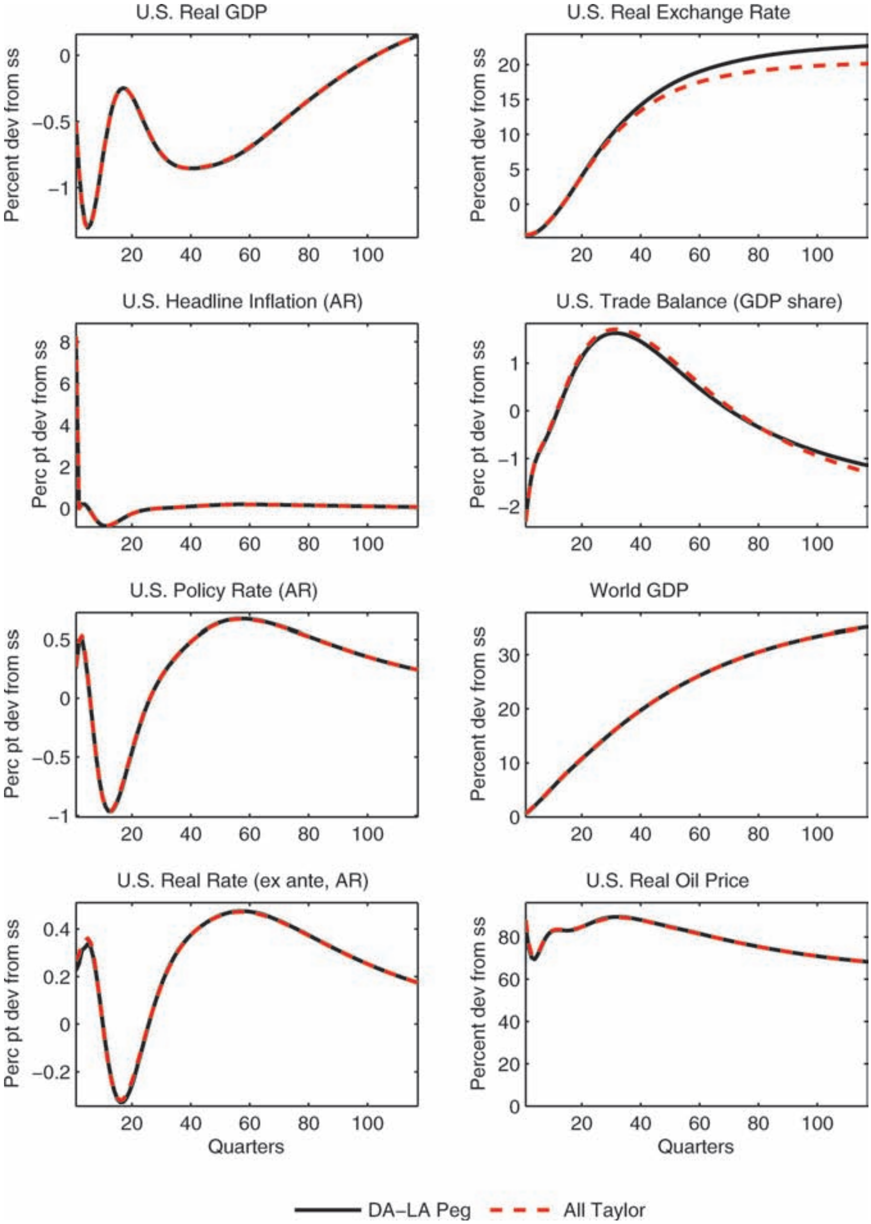
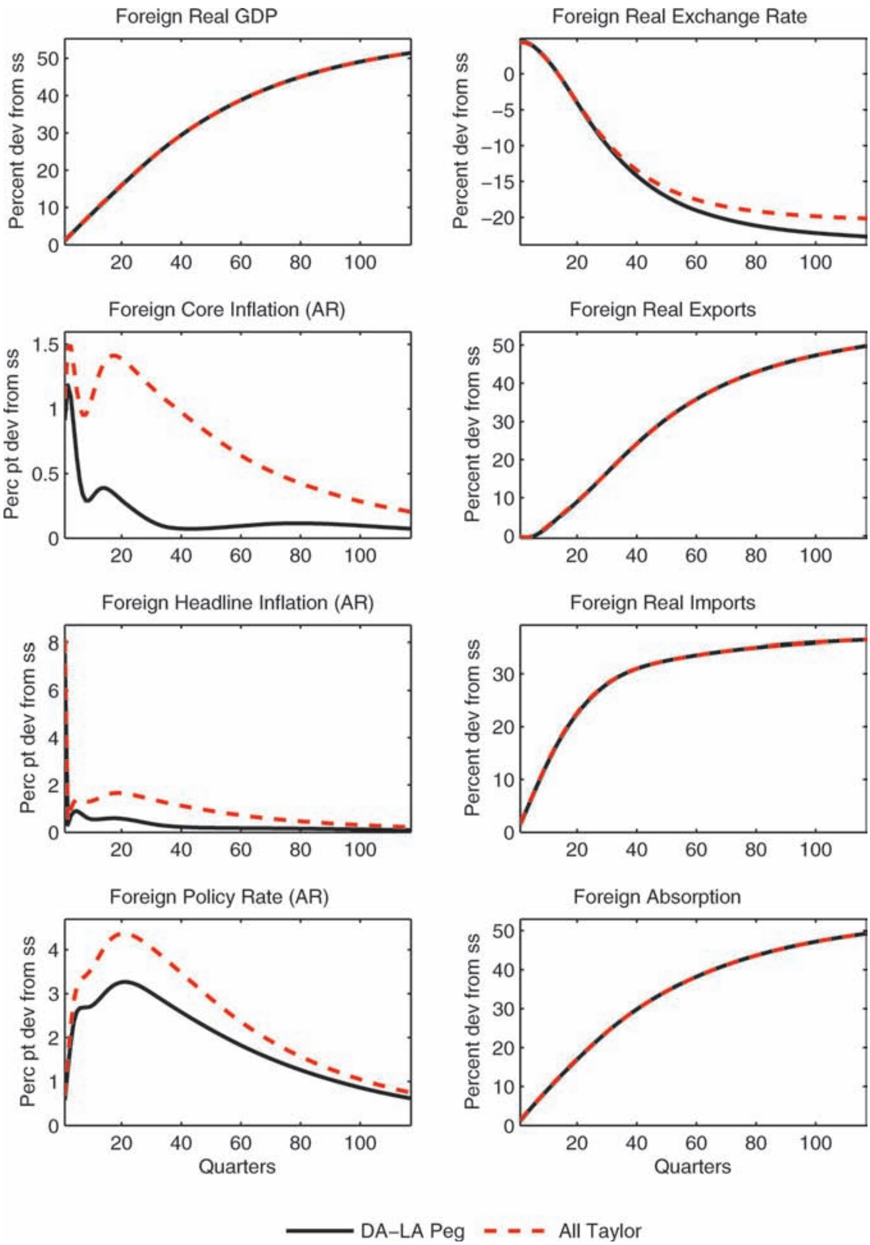


Figure 11. Foreign Technology Growth Shock (Aggregate Foreign Responses)



percentage points relative to baseline due to faster growth in technological progress abroad.[2] Given that the technology improvement occurs only in the foreign countries, this is consistent with a rise in world GDP growth of a little more than 1 percentage point. The size of the shock seems plausible in light of the surprisingly fast world GDP growth that occurred earlier in this decade. For instance, world GDP growth as estimated by the IMF's World Economic Outlook (WEO) rose from about 4 percent per year in 2003, roughly its historical average over the preceding two decades, to an average pace of over 5 percent per year in the 2004–08 period. Although explicit longer-term forecasts for world growth are not provided in the WEO, our reading of the evolution of short-term world growth forecasts and the associated commentary in successive editions of the WEO over the 2003–08 period is that much of the faster growth was a surprise and was eventually reflected in upward revisions to projections for potential growth in China and some other key economies.

Figure 10 shows that the shock eventually pushes up the level of world GDP by a little more than 30 percent over the thirty-year simulation horizon depicted (even though U.S. GDP actually declines a bit, as the stimulative effect of an improvement in real net exports is offset by higher real interest rates and oil prices, which depress U.S. investment for a prolonged period). The higher level of world GDP in turn causes oil prices to rise both persistently and by a large amount. By the end of the simulation horizon, the oil price remains nearly 70 percent above its baseline value. The magnitude of the increase reflects our assumption of a long-run demand elasticity of 0.5 for oil and the rise in world GDP of over 35 percent. The responses in the figure are virtually indistinguishable whether or not the dollar bloc pegs to the U.S. dollar or follows an independent Taylor rule. This reflects that the two alternative policies imply very similar paths for the real interest rate in the dollar bloc.

Although the initial rise in the oil price is a bit larger than the long-term response, overall the projected trajectory is reasonably flat. The growth rate shock produces a persistently elevated level path precisely because substitution away from oil associated with higher prices is almost completely offset by increased demand

[2]The shock to the growth rate of technology in each of the foreign country blocs follows an AR(1) with persistence of 0.95.

stemming from the increase in activity. With agents in the model expecting this flat trajectory, this scenario appears consistent with market expectations for oil prices actually observed during much of the 2004–08 period (as proxied by futures prices).

Our analysis also suggests that adverse shocks to the supply of oil may work in a parallel fashion to generate a highly persistent rise in oil prices, provided these shocks are sustained. Recalling figure 4, world oil production grew at a historical rate of roughly 1–1/2 to 2 percent per year through the first few years of this decade, but has subsequently declined in absolute terms due to particularly disappointing supply responses in non-OPEC countries. Moreover, while the limited forecasts of long-term oil supply available from the early part of this decade seemed consistent with a projection that oil supply would continue to expand roughly in line with its historical average, recent projections (including qualitative assessments) suggest a dismal outlook for growth in global supply. Notwithstanding that oil prices in late 2010 remained more than double their level of a few years ago, many analysts now project that the poor growth performance of the past few years will continue in the longer term. The IEA's 2008 *World Energy Outlook* projected that world crude oil output would be 75 million barrels per day in 2030, only a marginal increase from the local peak of 70 million barrel per day produced in 2007.

Accordingly, figures 12 and 13 investigate the implications of a persistent decline in the growth rate of world oil production of about 1–1/2 percentage points (that dies away very gradually, similarly to the productivity growth shock).[3] The contraction in world supply of over 20 percent after thirty years causes the oil price to rise nearly 40 percent by the end of the simulation horizon. The path of the oil price is relatively flat, as substitution away from oil due to higher prices is roughly counterbalanced by continued falls in supply. The results are little changed even if the dollar bloc follows a Taylor rule instead of pegging to the U.S. dollar.

Finally, it is interesting to consider the combined effects of faster-than-expected world GDP growth and weaker-than-expected growth in oil supply. This simulation is presented in figure 14. The

[3]The shock to the growth rate of oil supply follows an AR(1) with persistence of 0.98.

Figure 12. Oil Supply Shock in ROW Bloc

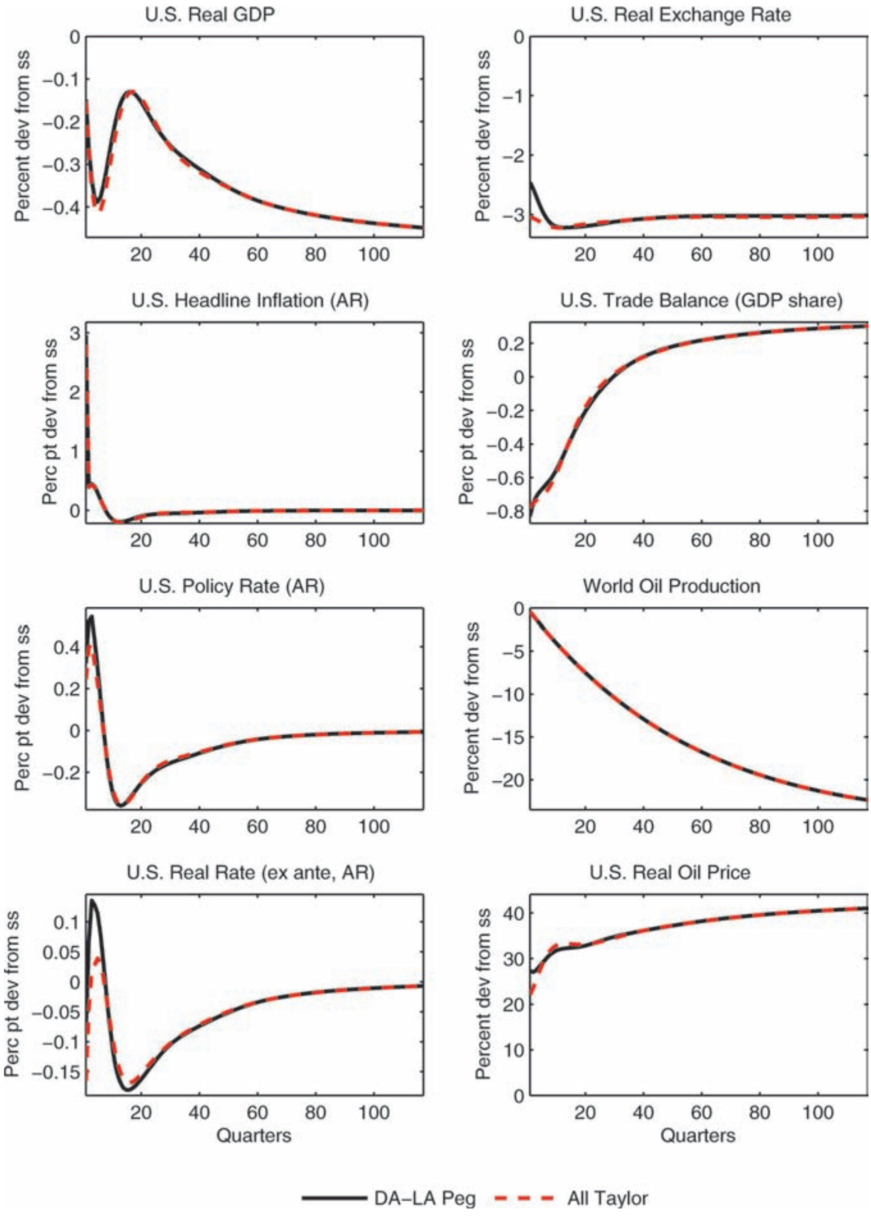


Figure 13. Oil Supply Shock in ROW Bloc (Aggregate Foreign Responses)

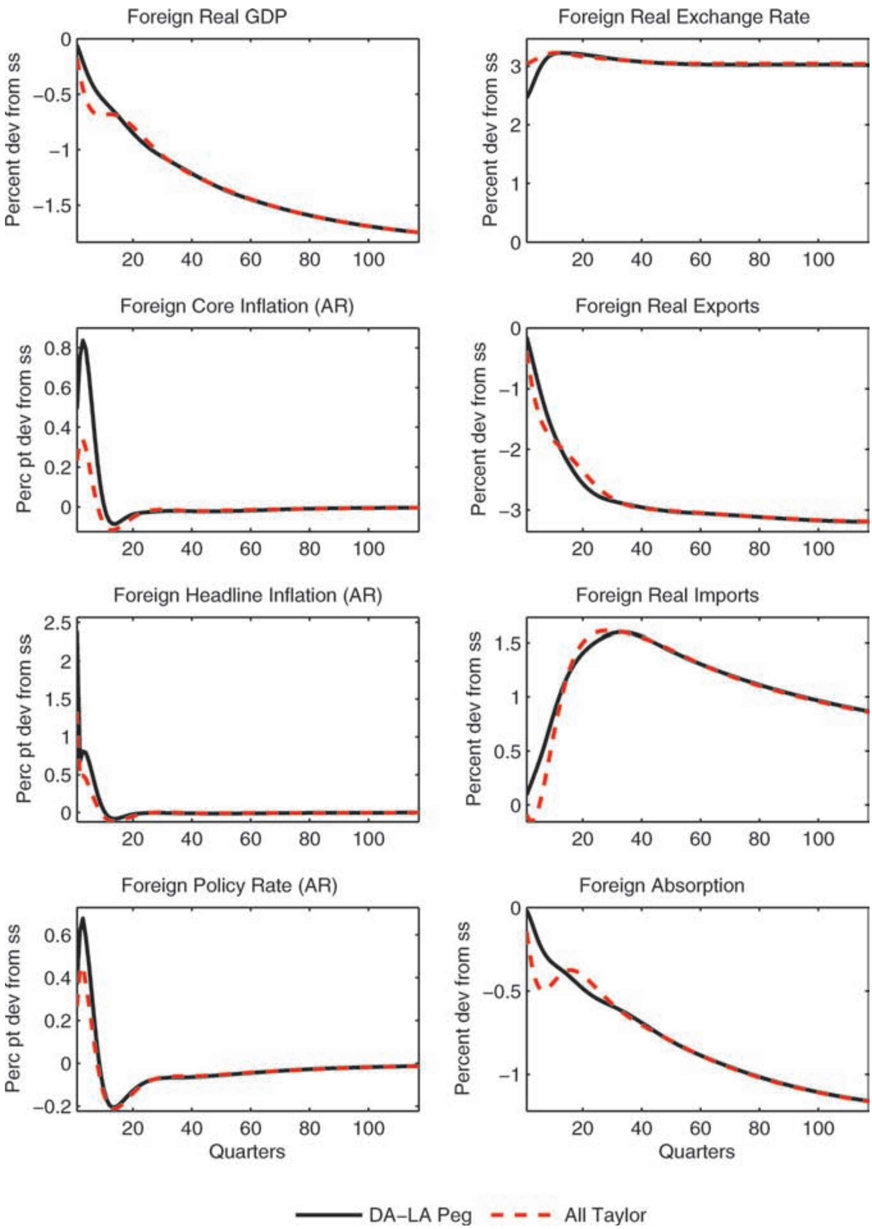
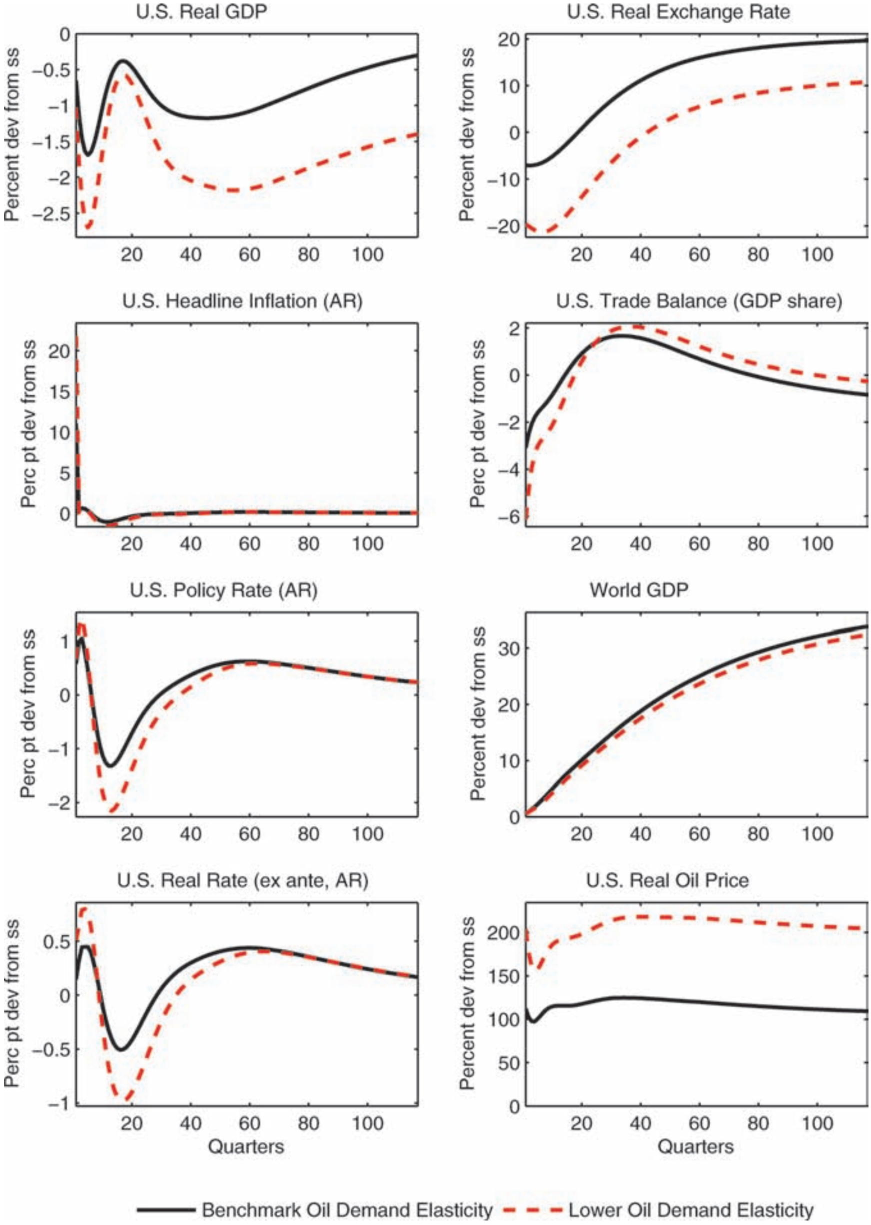


Figure 14. Foreign Technolgoy Shocks and Oil Supply Shock in ROW Bloc



simulation indicates that the combined shocks can account for more than a 100 percent rise in the oil price in the long run. The simulation reported by the dashed lines in figure 14 considers the effects of the same shocks but assuming a lower long-run price elasticity of demand for oil, equal to 0.3 (still in the range of empirical estimates). In that case, the oil price rises as much as 200 percent in the long run.

As highlighted above, our modeling framework lacks certain realistic features such as oil inventories and variable capacity utilization in oil supply. However, these features should not influence the long-run oil price response to persistent shocks. The main message is that faster-than-expected world GDP growth and weaker-than-expected growth in oil supply appear to offer a plausible rationale for much of the large and apparently permanent increase in oil prices that has occurred since 2003.

4. Conclusion

In this paper, we assessed the view that because many developing countries peg their currencies to the dollar, earlier this decade they were forced to loosen monetary policies in line with that in the United States, leading to economic overheating, increases in the demand for oil, and thus sustained rises in oil prices. Using the multi-country SIGMA model, we found that even if many developing country currencies were indeed pegged to the dollar, an easing of U.S. monetary policy would lead to only a transitory run-up in oil prices. The effect on oil prices is short lived both because loose monetary policy can keep output above its equilibrium level for only a limited period of time, and also because the run-up in oil prices induces demand adjustments that subsequently allow prices to come down.

A key lesson of our analysis is that it would take sustained and fundamental shocks to the demand and supply of oil to explain the persistent rise in its price through much of the decade. The more persistent responses of the price of oil to these shocks makes them more plausible candidates to explain the run-up in oil prices than the “dollar bloc” hypothesis.

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Discussion of "Did Easy Money in the Dollar Bloc Fuel the Oil Price Run-Up?"

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1. Introduction

This paper addresses a traditionally sensitive issue concerning the international spillovers from the U.S. monetary policy. The issue is sensitive because many observers feel that U.S. monetary authorities make decisions that have potentially large consequences for the global economy, almost exclusively based on domestic considerations. In the early 1980s, for instance, the focus of the debate was on the high interest rate policy pursued by Chairman Volcker to stem U.S. inflation, soon followed by the debt crisis in the developing world. In the 1990s, similar concerns were raised in relation to the monetary contraction in the United States which preceded the Mexican debt crisis. In the new millennium, the focus is on the consequences of the prolonged phase of U.S. monetary expansion (rather than contraction)—an expansion that many find excessive even from a purely U.S. domestic perspective.

The specific question addressed by the paper is whether, among other things, low interest rates in the United States since 2004 fueled a commodity price boom. The transmission mechanism—from the expansionary monetary stance to oil prices—is best understood against a general context in which there are other, non-monetary factors also at work. These are the factors that explain high rates of energy-intensive growth in emerging-market economies. Against a background feeding expectations of high prices for energy and commodities, low U.S. rates (i) may have provided "fertile ground for speculation," if anything, by keeping the cost of holding inventories low; (ii) together with dollar depreciation, may have reduced the incentives to extract today rather than in the future; and (iii) most importantly, may have contributed to the overheating of the economies pegging to the dollar, which happens to be economies where growth is most energy intensive.

2. An Exercise in Optimal Currency Area Theory

In a nutshell, the paper presents a modern version of an exercise in the optimal currency area (OCA) theory. The main question of interest concerns the global macro implications of asymmetric shocks hitting the country at the center of an international monetary network of currency pegs, which accounts for about 20 percent of the world economy. Different from conventional OCA studies, the answer is built on New Keynesian foundations.

The world economy consists of three blocs: the United States (as the center country), a dollar bloc, and the rest of the world (the non-dollar bloc). The authors posit an exogenous country-specific recessionary shock in the United States, large enough to cause the Federal Reserve to cut interest rates by 2 full percentage points for a number of years (a measure desirable from a domestic perspective). The economies pegging to the dollar adjust their monetary stance accordingly and thus overheat (since they suffer no recessionary shocks).

While fitting conventional wisdom in many dimensions, the exercise also yields a non-obvious result. Namely, monetary overheating in the dollar bloc translates into a sharp rise in oil prices, despite the contained weight of these economies in the world economy and the large recessionary shock in the center country. This is a striking result—fitting the unusual evidence of a commodity price boom during a U.S. recession.

However, the real effect of monetary policy predicted by the model is short lived. In other words, the model suggests that the monetary expansion is unlikely to explain the persistence of the oil rise observed in the data.

3. Features of the Model

To fully appreciate these results, it is appropriate to discuss briefly four key features of the model. First, the model assumes that the nominal price of imports is sticky in local currency—a hypothesis usually dubbed "local currency pricing," or LCP.

In the early debate on open-economy macro, some studies have considered LCP as a possible reason for a country to pursue a currency peg. If (because of LCP) nominal rigidities in local currency limit the extent to which exchange rate movements can redirect demand across borders, it might be possible that the costs of giving up exchange rate flexibility are quite contained. Indeed, in some circumstances (e.g., if the basket of consumption goods is similar across countries, and shocks only hit productivity), the optimal policy actually implies that the exchange rate remains stable (see the discussion in Duarte and Obstfeld 2008 and Corsetti 2006).

We now understand that the results underlying the conjecture that LCP would motivate a fixed exchange rate are quite special. In general, LCP is not a reason to peg the currency. On the contrary, with an optimal policy in place, exchange rate variability may actually be higher under LCP than under the alternative (classical) hypothesis that goods prices are sticky only in the currency of the producers. These issues are analyzed in detail in the chapter that Luca Dedola, Sylvain Leduc, and I have written for the *Handbook of Monetary Economics* (Corsetti, Dedola, and Leduc 2011).

Correctly, the authors introduce the LCP hypothesis in the analysis as a way to keep the model close to the evidence (although the data also point to an asymmetry in the degree of pass-through across countries), not to motivate the dollar bloc. If anything, the results of the paper clearly stress undesirable consequences of pegging to the dollar.

Second, the model includes a parsimonious specification of the oil sector, which abstracts from "speculation" and oil supply decisions. Of course, there could be key interactions between demand and supply decisions—a subject that the authors will hopefully develop in another paper.

Third, financial markets are posited to be (exogenously) incomplete: agents can borrow and lend across borders trading a bond. As explained in the new *Handbook of Monetary Economics*, financial imperfections map into relative price misalignments and demand imbalances, creating potentially important trade-offs for monetary policymakers.

In Corsetti, Dedola, and Leduc 2010, for instance, with international trade in one bond, persistent asymmetric supply shocks in one region have very large effects on relative wealth and demand across borders (compared with both complete-market and financial-autarky economies). Under a reasonable calibration of the model, the fact that households and firms can borrow in anticipation of higher future income and productivity translates into strong demand imbalances which appreciate the country's real exchange rate. By the same mechanism (a boom in domestic demand), real shocks in the model under consideration appreciate the price of resources in fixed supply (oil). Not only the wealth wedge resulting from real shocks is in stark violation of efficient risk sharing. Real disturbances also result in large misalignment of relative prices, in turn amplifying the inefficient divergence in wealth.

The magnitude of the effects is especially large, by virtue of a fourth assumption, regarding the price *elasticity* of oil demand (in production and investment). This elasticity is assumed to be low in the short run but rising over time (in line with foreign trade). Such an assumption, which fits independent evidence, underlies the sharp equilibrium price adjustment to shocks on impact.

The reason why, in an incomplete-market environment, a low trade elasticity in the short run amplifies the consequences of financial imperfections rests on the implied strength of "income effects" in the transmission of shocks. This theoretical point has been analyzed in general in previous joint work of Dedola and Leduc (Corsetti, Dedola, and Leduc 2008). It has been revisited in the context of a general equilibrium model with oil production by Bodenstein, Erceg, and Guerrieri 2011. The latter contribution nicely illustrates the interpretative potential of models placing relative wealth effects at the core of the international transmission of shocks in the oil sector.

4. Explaining Persistence

As already mentioned, a key result of the model is that monetary expansion alone cannot explain the persistence in the oil price rise observed in the data. This is true despite the fact that the authors make sure to include in the model features producing "persistence" in a number of dimensions, including habit in consumption, adjustment costs in investment, a backward-looking component in the Phillips curve, and the like.

Based on the model, other "stories" seem to match the evidence much better. In particular, the authors stress the role of persistent positive shocks to productivity (raising permanent income) or persistent negative shocks to supply. Note that these shocks would have long-lasting effects on oil prices whether global or specific to the dollar bloc.

A prediction of the model worth stressing is that, in response to these real shocks, the price of oil remains rather flat over time. This follows from the fact that two forces offset each other dynamically. On the one hand, as the oil price elasticity becomes higher, firms and households substitute away from oil. On the other hand, as economic activity becomes stronger, a higher aggregate demand sustains the demand for oil, against the negative implications of a higher price.

Nonetheless, one could note that, while most of the discussion of the model referred to the period 2004–07, the quotations motivating the analysis are actually specific to the period between the end of 2007 and the summer of 2008. The short-lived oil price increase predicted by the model is not too far from the evidence for this period.

At face value, the results from the quantitative exercises are actually quite insightful into the economics of the first few quarters of the global crisis. The Federal Reserve did slash rates after the eruption of the crisis, and the dollar bloc did boom for many months; there is little doubt that expectations of asymmetric growth in Asia (and emerging markets) contributed to the commodity price booms. Of course, the financial sector was in turmoil. Yet, in that period, there was widespread hope that liquidity supports with some occasional bail-out would be the right medicine to help the international financial system metabolize the toxic assets and overcome the financial crisis rather smoothly (a hope that vanished in the fall of 2008).

5. Open Issues for Future Research

It is well known that the New Keynesian theory has limits in accounting for persistent effects of monetary policy. To assess the results of the paper more fully, one may wonder whether there is some fundamental characteristic of the economy that, by construction, is left out of the analysis.

An obvious instance of a distortion that is not yet encompassed in the model (at least to my knowledge) is the possibility of bubbles, which would of course lead to a systematic rethinking of optimal policy design.

But even independently of bubbles, it is still possible that financial imperfections create large and persistent mispricing and misallocation, in the form of fundamental imbalances at both domestic and international levels. These distortions in turn may exist because monetary policy is sub-optimally conducted, in the sense that it fails to take into account the relevant policy trade-offs—for many reasons.

In an economy with frictionless financial markets, the main task of monetary policy consists of addressing the distortions posited by nominal rigidities. With financial imperfections instead, the interaction of monetary and real distortions posits a powerful challenge to monetary policy—but may also create opportunities for the policymakers to redress fundamental misallocation and mispricing. I have little doubt that the profession will soon make substantial progress in refining our understanding of monetary and real transmission, and in redefining the objectives and strategies of monetary policy, at the national and global level.

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Did the Crisis Affect Inflation Expectations?*

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We investigate whether the anchoring properties of long-run inflation expectations in the United States, the euro area, and the United Kingdom have changed around the economic crisis that erupted in mid-2007. We document that survey-based measures of long-run inflation expectations remained fairly stable around 2 percent in the euro area, fluctuated above 2 percent in the United States, and drifted up to about 2.5 percent in the United Kingdom. Expectations measures extracted from inflation-indexed bonds and inflation swaps became much more volatile in 2007. Moreover, structural break tests show that their sensitivity to news about inflation and other domestic macroeconomic variables—a measure of anchoring—increased during the crisis, and in particular during the heightened turmoil triggered by the collapse of Lehman Brothers. While liquidity premia and technical factors have significantly influenced the behavior of inflation-indexed markets since the outburst of the crisis, we show that these factors did not contaminate the relationship between macroeconomic news and financial market-based inflation expectations at the daily frequency. While our evidence is consistent with the idea that long-run inflation expectations may have become less firmly anchored during the crisis, problems in measuring expectations accurately make it difficult to draw definitive conclusions.

JEL Codes: E31, E44, E52, E58.

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1. Introduction

"Ultimately, the firm anchoring of inflation expectations remains the best way to check the appropriateness of monetary policy in an uncertain environment." (Bini-Smaghi 2009)

After rising sharply in 2007 and the first half of 2008—against the background of rallying commodity and food prices—global inflation went on a marked downward trend when the macroeconomic consequences of the financial crisis became visible in the fall of 2008. A few months later, price changes turned negative in a number of economies, sparking a debate on whether deflationary risks were likely to materialize and what steps would be needed to avoid deflation (Jeanne 2009). The discussion centered to an important extent on how inflation expectations were affected by the crisis, and in particular on whether the anchoring properties of long-run inflation expectations changed as the crisis unfolded (Svensson 2009). Our paper attempts to answer this question, by examining the behavior of long-run inflation expectations in three major economies—the United States, the euro area, and the United Kingdom—in the years around the crisis.

We proceed in two steps. We first examine the time-series behavior of two types of measures of long-run inflation expectations—survey-based measures and measures extracted from financial market instruments—for the United States, the euro area, and the United Kingdom. In particular, we check whether the two measures vary around central banks' inflation objectives. The former are available at semi-annual frequency, while information extracted from financial markets is available at daily or even intraday frequency. Markets for inflation-indexed bonds and swaps in these economies are the most liquid in "normal" times and have enjoyed sufficient liquidity to allow extracting "reasonable" measures of inflation compensation from them.

In the second step, we follow the approach of Gürkaynak, Sack, and Swanson (2005), Gürkaynak, Levin, and Swanson (2010), and Beechey, Johannsen, and Levin (forthcoming), and investigate the reaction of financial market-based measures to news about inflation and other domestic macroeconomic variables. The idea is that if long-run inflation expectations are perfectly anchored, they should not react to the arrival of news but rather be stable around the central bank's target for inflation. In particular, we test whether the reaction of expectations to news has changed since the outburst of the crisis. Statistically and economically significant evidence of such a change would indicate that the crisis has influenced market participants' perception of the Federal Reserve's, the Bank of England's, and the European Central Bank's (ECB's) commitment to price stability. One conjecture is that the unprecedented monetary easing (through both conventional and non-standard monetary policies), coupled with the accumulation of a huge fiscal debt, may have undermined market participants' confidence in the ability of central banks to keep inflation at target in the longer run.

We find two main empirical results. First, consistently with evidence presented in Beechey, Johannsen, and Levin (forthcoming), survey-based measures of long-run inflation expectations point to different expectation dynamics in the three economies. In the euro area, they remained fairly stable within the central bank's comfort zone both during the oil price rally in 2006–07 and as the crisis unfolded, although their cross-sectional dispersion increased sharply in early 2009. In the United States, survey-based measures fluctuated above 2 percent during the whole sample period, and cross-sectional dispersion seems to have risen. In the United Kingdom, the level of survey-based measures of long-term inflation expectations has drifted up.

Second, financial market-based measures became much more volatile around mid-2007. Moreover, structural break tests show that inflation expectations became more sensitive to macroeconomic news, particularly during the heightened turmoil triggered by the collapse of Lehman Brothers. We find that liquidity premia and technical factors appear to have significantly influenced the behavior of measures of inflation expectations derived from inflation-indexed bonds or inflation swaps since the outburst of the crisis. At the same time, they do not appear to have contaminated the relationship at the daily frequency between macroeconomic news and financial market-based inflation expectations.

In the absence of formal tests, we cannot use our graphical evidence on survey-based measures of inflation expectations to draw firm conclusions on the anchoring of expectations during the crisis. This said, the observed trends in these variables are consistent with the idea that long-term expectations may have become somewhat less firmly anchored in the United States and the United Kingdom during the crisis, especially when compared with the euro area. Similarly, our understanding of day-to-day changes in financial markets remains far from perfect, and shifts in liquidity are not easily distinguishable from shifts in long-run inflation expectations or perceived inflation risk. Hence, results on financial market-based expectations measures also have to be interpreted with great caution. Subject to these caveats, our evidence on structural breaks in regressions estimated with financial market-based expectations measures suggests that in all three areas, long-run inflation expectations may have become less firmly anchored during the crisis.

Differences between the dynamics of survey-based measures and measures derived from financial instruments—particularly for the euro area—may at least in part stem from difficulties in accurately measuring expectations but could also reflect important differences in the formation of expectations across different types of agents. Understanding this heterogeneity and its implications for policymakers is an important avenue for future research.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the relevant literature on the anchoring of inflation expectations. Section 3 describes two measures of long-run inflation expectations: survey-based measures and measures backed out from financial instruments. Section 4 discusses the role of liquidity and technical factors in financial market measures of inflation expectations. Section 5 presents our empirical model and the main results. Section 6 concludes.

2. Literature Review

While expectations and credibility play a central role in the theoretical literature, there is little theoretical work on the concept of "anchoring" of inflation expectations. In standard macroeconomic theory, if the central bank's objective function is known and constant, the rational expectations hypothesis implies that long-run inflation expectations do not change over time in response to the arrival of new information. In fact, Del Negro and Eusepi (2009) show that standard medium-scale dynamic stochastic general equilibrium models have difficulties explaining the evolution of inflation expectations, and that the fit is even worse when the assumption of perfect information is relaxed. In recent years, a series of papers departed from the rational expectations hypothesis and the assumption of a known and constant central bank objective (e.g., Orphanides and Williams 2005; Brazier et al. 2008; Demertzis and Viegi 2007; Demertzis, Viegi, and Marcellino 2008). This approach allows more realistic models of the link between inflation expectations and underlying inflation.

A key element of these models is the relationship between inflation expectations and shocks to the economy. The higher the sensitivity of expectations to these shocks, the more successful monetary policy will be. In Orphanides and Williams (2005), agents do not know the true model of the economy but rather constantly update their estimates based on all information available to them. As a result, inflation expectations are sensitive to economic shocks. Orphanides and Williams (2005) introduced central bank communication in their model and find that with learning, successful communication reduces the sensitivity of inflation expectations to actual inflation.

A similar idea is found in Demertzis and Viegi (2007), who modeled monetary policy as an information game in which individual agents have to interpret new (publicly available and private) information when they form ex ante expectations about future long-term inflation. In their model, ex post inflation is a function of the monetary policy chosen by the central bank to pursue its objectives and the average of all individual expectations. It is then optimal for agents to form expectations based on three elements: monetary authorities' objectives and their policy decisions; shocks that occur after these decisions; and the average of individual inflation expectations. Once the central bank communicates its inflation objective to the public—such as the ECB's operational definition of price stability as below but close to 2 percent—agents can either form their expectations based on the above three elements or, alternatively, coordinate their expectations on that target. They derived a time-varying parameter that captures the credibility of the central bank's target. If the target's credibility is sufficiently high, individual agents will focus their expectations on that target.

In a companion paper, Demertzis, Viegi, and Marcellino (2008) took their model to the data and estimated the degree to which long-run inflation expectations in the United States have been anchored to the Federal Reserve's objective. They tested whether long-run inflation expectations—derived from the Federal Reserve's FRB model or quarterly survey-based measures—are influenced by short-run inflation dynamics. They estimated a time-varying parameter (λ) that measures the extent to which inflation expectations are anchored across quarters. They found that in recent years, the anchoring of expectations in the United States has weakened but only slightly, without compromising the Federal Reserve's credibility.

Agents may also use rules of thumb ("heuristics") to make inflation forecasts. Brazier et al. (2008) consider two heuristics: one is based on lagged inflation and the other on an inflation target announced by the central bank. In their model, agents switch between these two heuristics based on an imperfect assessment of how each has performed in the past.

The empirical literature on drivers of inflation expectations—surveyed carefully in a paper by Clark and Davig (2008)—has highlighted the role of macroeconomic variables.[1] The periodical announcements on the state of the economy and forecasts released by various (statistical) offices and agencies form a steady source of new information. To the extent that the new information is unanticipated, beliefs about future inflation may be updated. If expectations are perfectly anchored—i.e., the central bank credibly commits to its inflation objective—long-run inflation expectations should not be responsive to news about actual inflation or, more general, about macroeconomic conditions.

A number of recent studies documented the anchoring of long-run inflation expectations in a number of countries. One strand of the literature relies on inflation surveys. Levin, Natalucci, and Piger (2004) analyzed the behavior of private-sector inflation forecasts at horizons up to ten years—measured by quarterly Consensus Forecasts—in United States and the euro area over the period 1994–2003. They found that expectations were highly correlated with a three-year moving average of lagged inflation. By contrast, in industrial countries that have adopted inflation targeting (United

[1] Another strand of literature relies on economic experiments (e.g., Marimon and Sunder 1994; Hommes et al. 2005, 2007; Adam 2007).

Kingdom, Sweden, Canada, Australia, and New Zealand), inflation expectations were found not to be sensitive to actual inflation. Levin, Natalucci, and Piger (2004) concluded that inflation targeting has played a significant role in anchoring long-run inflation expectations. Paloviita and Virén (2005) found that inflation expectations, proxied by OECD inflation forecasts, respond to changes in output and actual inflation. Their results are based on a simple vector autoregression model with inflation, inflation expectations, and the output gap, estimated with pooled annual data for euro-area countries over the period 1979–2003. Clark and Nakata (2008) showed that in the United States, inflation expectations appeared to be slightly better anchored in recent years compared with twenty or more years ago. In particular, they found evidence of a declining impact of unexpected increases in inflation on long-term expectations.

A second strand of the literature extracted inflation expectations from inflation-indexed financial market instruments, and looked at the relationship between inflation expectations and macroeconomic variables at high (daily or intraday) frequency (Swanson 2006). Gürkaynak, Sack, and Swanson (2005) derived inflation expectations from inflation-indexed bonds and examined their sensitivity to surprises about macroeconomic announcements at the daily frequency. To test for anchoring of inflation expectations, they regressed daily inflation expectations on a set of macroeconomic news variables. They found that between 1990 and 2002, long-run inflation expectations in the United States were not perfectly anchored. This analysis was extended by Gürkaynak, Levin, and Swanson (2010) and Gürkaynak et al. (2006), who documented that long-run inflation expectations are more solidly anchored in the United Kingdom, Sweden, and Canada—countries that adopted formal inflation targets. Consistently with Levin, Natalucci, and Piger (2004), they concluded that a numerical inflation target has helped anchor long-term inflation expectations.

Beechey, Johannsen, and Levin (forthcoming) followed the same methodology to compare the anchoring properties of long-run inflation expectations in the United States and the euro area over the period June 1, 2003–December 31, 2006. They found that surprises about monetary policy decisions and macroeconomic data releases—the core CPI but also indicators of economic activity such as the National Association of Purchasing Managers (NAPM) index or non-farm payrolls—have significant effects on U.S. forward inflation compensation at different horizons. By contrast, long-term inflation compensation does not significantly react to any news about price or output developments in the euro area. A similar picture emerges from graphical evidence on medians and dispersions of survey-based inflation expectations in the United States and the euro area. Beechey, Johannsen, and Levin (forthcoming) concluded that long-run inflation expectations are more firmly anchored in the euro area than in the United States.

This paper builds on the literature by developing a method to assess possible changes in anchoring of inflation expectations around the recent crisis. Mounting inflationary pressure due to booming commodity prices in the run-up to the crisis might have caused inflation expectations to drift. Similarly, the crisis may well have led to drifting inflation expectations in the wake of unsurpassed monetary and fiscal expansion.

3. Measuring Inflation Expectations

3.1 Survey-Based Measures

There are two main approaches to measuring long-run inflation expectations. A common approach relies on inflation surveys.[2] A frequently used data source, Consensus Economics, provides semi-annual data on expectations of a panel of some thirty professional forecasters six to ten years ahead, for a number of countries. There are also survey data for somewhat shorter horizons. For example, at a horizon of five years, the ECB Survey of Professional Forecasters (SPF) collects, on a quarterly basis, forecasts by a panel of some seventy professional forecasters on euro-area HICP.

Survey measures have several important shortcomings. First, given their low frequency, survey measures appear well suited for analyzing longer-run properties of inflation expectations but not for identifying the existence and timing of breaks in the expectation formation over a short horizon. Second, survey results may not be

[2] For a detailed analysis of the properties of these measures, see European Central Bank (2006) and Clark and Davig (2008).

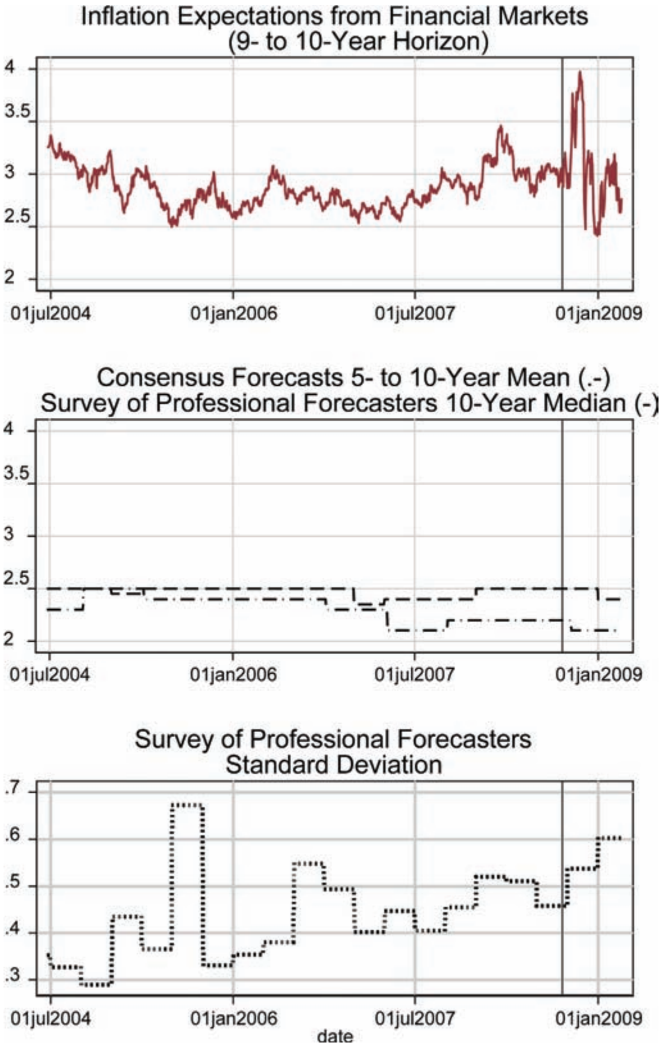
reliable to the extent that respondents do not have to act on the basis of their responses—i.e., "do not put their money where their mouth is."[3] Third, as shown by van der Klaauw et al. (2008), survey results are sensitive to the wording of the questions. Fourth, different types of survey measures may produce very different results. Mankiw, Reis, and Wolfers (2004), for example, looked at fifty years of data on inflation expectations in the United States, and documented substantial disagreement among both consumers and professional economists about expected future inflation. They found that this disagreement varied substantially through time, depending on the level of inflation, the absolute value of the change in inflation, and relative price variability.

Figures 1–3 show survey-based measures of inflation expectations in the United States, the euro area, and the United Kingdom around the crisis. For each area we included the measures with the longest horizon available. Each graph plots the mean value of inflation forecasts from Consensus Economics between five and ten years ahead. For the United States and the euro area we also included in the middle panel the SPF expectations at five years from now and over the next ten years. For SPF expectations we also obtained a measure of the cross-sectional dispersion given by the standard deviation of respondents' answers, which is plotted as the dotted line in the bottom panel.

As documented also in Beechey, Johannsen, and Levin (forthcoming), these graphs suggest that long-term inflation expectations followed different dynamics around the crisis in the three economies. In the euro area, expectations remained fairly stable within the ECB's comfort zone both during the oil price rally in 2006–07 and as the crisis unfolded. Their cross-sectional dispersion also did not change significantly. In the United States, survey-based measures always exceeded 2 percent, and both survey sources started to disagree on the long-run level of inflation starting in 2007. The dispersion of respondents of the SPF also started to rise somewhat during this period. In the United Kingdom, the level as expected by Consensus Forecasts respondents follows a remarkable upward trend that started in 2007. Moreover, while measures of dispersion of long-term

[3]This point is emphasized in the experimental economics literature on inflation expectations (Smith 1982).

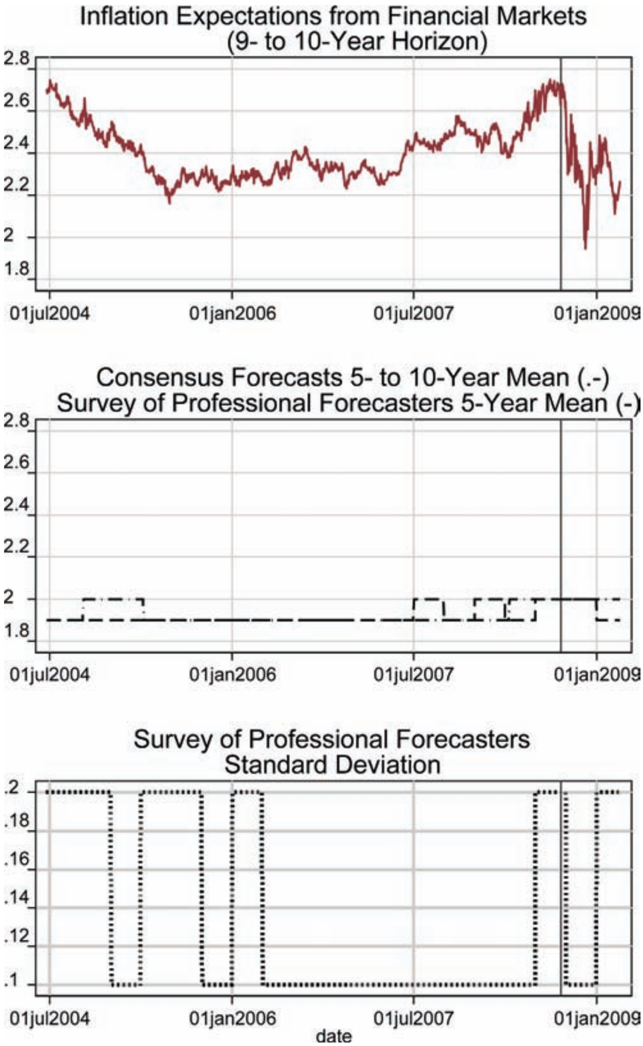
Figure 1. U.S. Inflation Expectations



inflation expectations are not available for the United Kingdom, recent issues of the Bank of England Inflation Reports show that the dispersion of nine-quarter-ahead inflation projections of professional forecasters has risen substantially over the past several years.

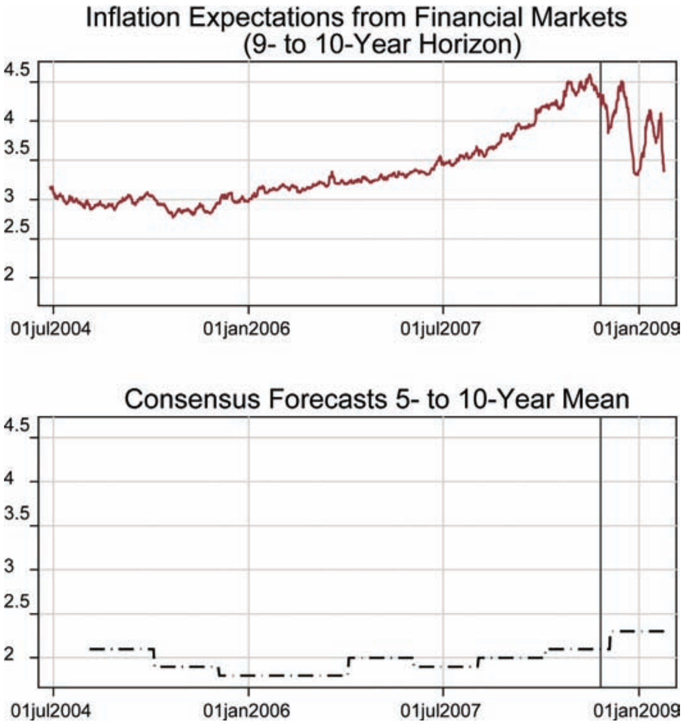
The limitations of survey-based expectations measures do not allow drawing strong conclusions from graphical evidence. Moreover,

Figure 2. Euro-Area Inflation Expectations



because of the low frequency of survey data, it is not possible to formally test changes in the anchoring properties of long-term expectations. This said, figures 1–3 are consistent with the idea that the anchoring properties of long-term inflation expectations may have changed in the United States and the United Kingdom during the

Figure 3. UK Inflation Expectations



crisis. By contrast, they seem to point to no changes in the anchoring of long-term expectations in the euro area.

3.2 Financial Market-Based Measures

A second approach to measuring long-run expectations consists in using financial market-based measures. In a number of countries, bonds or interest rate swaps that are linked to some measure of domestic inflation are actively traded (Deacon, Derry, and Mirfendereski 2004 and JP Morgan 2008). These instruments can be combined with nominal bonds or nominal interest rate swaps to back out financial markets' inflation expectations. The main advantage of this type of measure is that, given its high frequency, it allows examining more formally changes in the behavior of expectations over a relatively short horizon. It is therefore most useful in investigating whether the financial crisis has affected the anchoring of inflation expectations to the Federal Reserve's, the ECB's, and the Bank of England's inflation objectives.

In this paper we derived inflation expectations from nominal and inflation-indexed financial instruments. In particular, we considered inflation-indexed bonds for the United States (Treasury Inflation-Protected Securities, TIPS) and the United Kingdom (inflation-linked gilts), and inflation swaps for the euro area. These instruments are actively traded—the most liquid ones among inflation-indexed products.[4] For example, market commentary indicated that the monthly trading volume of ten-year euro-area inflation swaps averaged around six billion in 2007 (JP Morgan 2008). Buyers of inflation swaps primarily include insurance companies and pension funds, which suffer a loss of income if the actual inflation rate increases. Typical inflation swap sellers include firms whose income is linked to inflation while their expenses are not, or only to a lesser degree, such as public authorities, utilities, real estate companies, or distribution companies. By selling inflation in an inflation-linked swap, they are able to protect future income linked to inflation. Data for the yield curves of UK inflation-indexed bonds were taken directly from the Bank of England, while data on U.S. TIPS and euro-area swaps were obtained from Bloomberg.[5]

Here we describe in detail the method followed to extract inflation expectations from swaps markets, but the main features apply also to the approach we followed for bond markets. Inflation expectations can be measured by one-year zero-coupon forward rates of inflation swaps. Since we focus on long-term inflation expectations, we chose one-year zero-coupon forward rates ending ten years ahead. Hence, at day t inflation expectations are measured by

[4] Alternatively, we could have used nominal and inflation-indexed bonds also for the euro area, which in recent years have become increasingly liquid. Our preference for swaps is motivated by their greater liquidity along the whole maturity spectrum, particularly in the earlier years in our sample period. Beechey, Johannsen, and Levin (forthcoming) note that inflation compensation derived from swaps and TIPS are very similar. For a more extensive discussion of the difference between inflation-indexed bonds and inflation swaps, see Deacon, Derry, and Mirfendereski (2004) and JP Morgan (2008).

[5] See www.bankofengland.co.uk/statistics/yieldcurve/index.htm.

$$f_t = f^{is}_{t,10}, \tag{1}$$

where $f^{is}_{t,10}$ denotes the one-year zero-coupon forward rates ending ten years ahead for inflation swaps.

We collected daily data on euro-area swap markets for the period June 23, 2004 to March 24, 2009. For each day, swap rates are available for different maturities, allowing us to estimate a whole yield curve. The forward rates ending ten years ahead can be calculated from the swap rates with nine- and ten-year maturities as

$$f_{t,10} = \frac{(1+y_{10})^{10}}{(1+y_9)^9} - 1, \tag{2}$$

where y_9 and y_{10} are the nine-year and ten-year swap rates, respectively.[6]

One concern is that since the market for swaps with a nine-year maturity may be less liquid than the market for a ten-year maturity, estimates of forward rates based on nine-year swaps may exhibit a high level of noise. In order to filter out this noise, we followed a standard technique of the finance literature—the Nelson-Siegel method (see, e.g., Nelson and Siegel 1987)—to estimate a smoothed yield curve for each day. Details on this method are presented in appendix 1. Söderlind and Svensson (1997) argued that estimating yield curves by a simple curve fitting, as we did, rather than by a structural model for interest rate dynamics is appropriate when the purpose is to extract market expectations about future interest rates without making additional assumptions about the model structure.

We obtained a smoothed yield curve for each day for inflation swaps, from which we got the smoothed nine- and ten-year inflation swap rates. We then estimated ten-year-ahead forward rates for the inflation swaps, from which we derived a measure of inflation expectations. Note that our smoothing procedure is applied for each specific day, but it also gives a smoother measure of inflation expectations across time. This smoothing effect can be explained in terms of a smaller impact of liquidity effects. Throughout the paper, we used the smoothed series as a measure of long-run inflation expectations.

[6]The same formula to calculate the forward rates applies to both inflation swaps and interest swaps. This argument holds for the rest of the section.

Figures 1–3 show that our measures of long-run inflation expectations—based either on nominal and inflation-indexed bonds or on inflation swaps—differ significantly from the survey-based measures of inflation expectations. The expectations derived from financial markets are plotted in the top panel of each figure. The difference is most noteworthy in the euro area, where over the whole sample period, survey measures were very stable and close to the ECB's objective of medium-term inflation below but close to 2 percent. By contrast, inflation expectations derived from inflation swaps swung between 2 percent and 2.8 percent and became much more volatile after the onset of the crisis. Similarly, financial market and survey-based measures of long-run inflation expectations also differ visibly for the United States and the United Kingdom.

4. The Role of Liquidity Premia and Technical Factors

One potential reason for the visible difference between survey and financial market-based measures of inflation expectations is that the latter may be contaminated by other factors, especially during the crisis.[7] Break-even rates—i.e., the difference between nominal and inflation-indexed bonds—can be decomposed into four main factors: expected inflation, inflation risk premia, liquidity premia, and technical factors (Hördahl 2009). According to Hördahl (2009), the same applies to a much lesser extent to inflation-indexed swaps. One example of these technical factors is sudden portfolio shifts by leveraged investors that may affect nominal and inflation-indexed bond markets but are unrelated to changing views about future economic fundamentals. One critical assumption of exercises that back out measures of inflation expectations from financial instruments is that the last two factors do not respond to macroeconomic news at the daily frequency. Changes in far-horizon break-even rates can then be interpreted as a revision of market participants' long-run inflation expectations or inflation risk in response to new information, indicating that inflation expectations are not solidly anchored.[8]

[7] See, e.g., Barclays Capital Research (2008).

[8] Inflation risk reflects the volatility of inflation expectations as well as market participants' attitude toward risk. If inflation expectations are firmly anchored, neither of these two components should react to new information.

In “normal” times this assumption appears plausible. Dudley, Roush, and Steinberg Ezer (2009) documented the deepening of TIPS markets by looking at trading volumes, bid-ask spreads, and estimates of illiquidity premia. Beechey, Johannsen, and Levin (forthcoming) documented that the announcement effects on inflation expectations measured using TIPS or inflation swaps persist for about one business week. They interpreted this as evidence that the reaction of the dependent variable is not driven primarily by liquidity effects. Beechey and Wright (2008) decomposed U.S. nominal yields into three components—nominal yields, real yields, and the spread between these two (i.e., inflation compensation)—and then estimated the effect of news on these three components using intraday data. They found that different types of news—about prices, the real economy, or monetary policy—have quite different effects on real rates and rates of inflation compensation. In particular, only news about prices affects inflation compensation. They also tested whether the impact of news has changed over time, since the market for inflation-indexed bonds in the United States—Treasury Inflation-Protected Securities (TIPS)—has deepened. Their evidence suggests that the reaction of long-term inflation compensation to inflation news has not changed between February 17, 2004 and June 13, 2008, implying no significant change in inflation expectations’ anchoring properties during this period.[9]

During the current crisis, the assumption that changes in market liquidity and technical factors may contaminate the behavior of financial market-based measures of inflation expectations appears much less innocuous. Financial markets, including bond and swap markets, experienced pronounced swings in volatility and liquidity. In these circumstances, there was evidence that yields on nominal and inflation-indexed bonds (and swaps) were driven not just by expectations about future inflation but also by high and volatile liquidity premia and technical factors related, e.g., to hedging activity (Fender, Ho, and Hördahl 2009; Hördahl 2009).

[9]By contrast, using daily data from early 1999 to early 2004, Beechey and Wright (2008) compared the performance of their model before and after 2004 and found evidence that inflation compensation became less sensitive to news after 2004. They interpreted this result as suggesting that the improved liquidity and functioning of the TIPS market since 2004 may have allowed TIPS yields to become more responsive to new information.

Note that, by construction, our measure of inflation compensation filtered out part of the noise. In particular, by taking the difference between nominal and inflation-indexed bonds, we purged the effect of liquidity and technical factors that affect both markets in a similar way. For example, if on a particular day there is a sudden broad portfolio shift out of fixed-income markets in general and into equity markets, nominal and inflation-indexed bond yields could both be affected in a similar fashion. Moreover, we focus on day-to-day changes in inflation compensation, and the relative liquidity of the nominal and inflation-indexed markets may not change substantially from day to day. The same might be true for inflation swaps.

This discussion suggests that simple graphical evidence on the behavior of break-even rates can be misleading: the "true" inflation expectations may be anchored even though financial market-based measures are not close to the central bank's objective if the influence of liquidity and technical factors is not filtered out properly. In addition, even if our expectation measure is "accidentally" close to the central bank's objective, it is not sufficient to conclude that inflation expectations are firmly anchored. In this case, the movements of expectations are influenced by macroeconomic (and other) news, which happens to drive inflation expectations close to the central bank's objective. To get more accurate evidence on the anchoring of long-run inflation expectations, we therefore turn to examine their response to macroeconomic news.

5. Empirical Results on Breaks and Anchoring

In order to test whether inflation expectations became unanchored during the crisis, we examined the impact of news on HICP inflation and other macroeconomic variables on our measures of inflation expectations. Our focus is on testing for structural breaks while improving estimation by dealing explicitly with liquidity effects. Our sample period is June 23, 2004–March 23, 2009, and includes almost two crisis years during which liquidity effects may have been especially important.

Following the approach developed by Gürkaynak et al. (2006) and Beechey, Johannsen, and Levin (forthcoming)—who analyzed the credibility of the Federal Reserve, the ECB, and inflation-targeting central banks—we captured news by the difference between actual releases of the main euro-area macroeconomic variables and values anticipated by market participants according to surveys conducted by Bloomberg and JP Morgan. This is a common method in the literature, although Rigobon and Sack (2008) found that it tends to underestimate the responses to true news because of measurement errors. In fact, Bartolini, Goldberg, and Sacarny (2008) discussed shortcomings of survey-based measures of news but concluded that this approach may be the only one available in practice. We normalize the macro data surprises by the standard deviation of each series, which allows the coefficient estimates to be interpreted as the impact of a one-standard-deviation surprise in a given data release.

We expect that data releases on inflation variables are most important. However, without empirical guidance from the literature, we have few other priors on what type of information influences inflation expectations. Other macroeconomic variables—such as GDP growth, business confidence indicators, the unemployment rate, or wage growth—may also give indications about possible inflationary pressures. We used the same macro announcements as in Beechey, Johannsen, and Levin (forthcoming) with two exceptions. In the regressions where the dependent variable is euro-area or UK inflation expectations, we do not include U.S. news. Moreover, in our regressions with U.S. data, the macro news does not include oil futures.[10] For the euro area, we concentrated on data releases for the three main economies—Germany, France, and Italy—since these are most likely to have a primary influence on views on future euro-area inflation. Considerably more news variables are available through Bloomberg and JP Morgan for the United Kingdom and the United States. Appendix 2 lists all variables that were used.

We regressed our measure of long-run inflation expectations on a constant, a set of macroeconomic news variables, and a set of control variables, according to the following model:

$$\Delta f_t = \alpha + \beta \mathbf{X}_t + \gamma \mathbf{Z}_t + \varepsilon_t, \tag{3}$$

[10] Differently from Beechey, Johannsen, and Levin (forthcoming), we measure changes in inflation compensation in percentage points rather than in basis points.

where the dependent variable $\Delta f_t = f_t - f_{t-1}$ is the change, from closing of the markets at day $t-1$ to closing on day t, in one-year inflation compensation ten years ahead.[11] The explanatory variables $\mathbf{X}_t$ are a vector of news variables on various measures of the state of the economy. Most macroeconomic news arrives at 8:30 a.m., before stock markets open.[12] Our expectations variable therefore measures the change in inflation expectations between the end of the trading day before macro news arrives ($t-1$) and the end of the trading day on which the news arrives (t).

$\mathbf{Z}_t$ is a vector of control variables intended to capture the influence that shorter-term changes in liquidity premia and technical factors unrelated to inflation expectations may have on inflation swap rates, or on the difference between nominal and inflation-indexed bonds. In particular, our control variables are useful in purging the effect of liquidity premia and technical factors that are related to shocks that broadly hit financial markets. For example, a sudden increase in financial stress on a particular day due to news about the collapse of a major financial player may induce a broad flight to liquidity. This could benefit nominal bonds at the expense of other assets such as inflation-indexed bonds. Our preferred control variable is the implied volatility of bond yields, but we checked that our results were robust to using four alternative variables that measure market liquidity: the Chicago Board Options Exchange Volatility Index (VIX), a widely used measure of the implied volatility of S&P 500 index options; the euro-bund implied volatility; the on-the-run off-the-run spread (a commonly used measure of bond market liquidity); and analogously for the euro area, the KfU-bund spread.[13] All these non-news controls were first-differenced as well, because a change in implied volatility should lead to an additional change in our measure of inflation expectations through a liquidity premium.

[11]Since heteroskedasticity-consistent standard errors can be misleading when the explanatory variable only has few non-zero values, we use conventional ordinary least squares (OLS) standard errors. Using these rather than heteroskedasticity-consistent standard errors does not affect our results substantially.

[12]See, for example, JP Morgan (2009).

[13]For a detailed description of this variable, see Hördahl (2009).

We also controlled for day-of-the-week effects, but these turned out not to be statistically significant.[14]

We interpret a high R^2—to the extent that it is driven by significant coefficients on the variables X_t and that the level of inflation expectations differs significantly from the central bank's comfort zone—as evidence that expectations are weakly anchored. A low R^2 conversely implies well-anchored inflation expectations. A change in explanatory power of the model during the sample period would then indicate that anchoring properties of inflation expectations have changed. In particular, we verified whether the sensitivity of inflation expectations to news about inflation and other macroeconomic variables increased in 2006, when first commodity and food prices started to rally, and in 2007, when the financial crisis erupted.

To detect such changes, we need to test for a structural break. We used the Chow test, which verifies whether the structure of the model changes on a certain day. However, this is an ex post test in the sense that the timing of the break must be chosen with some prior knowledge. Chow tests for dates that are close to the real structural break will also give statistically significant results. To get a more precise indication of the timing of the structural break, we therefore used a rolling version of the Chow test.[15] Changing the date at which we split the sample gives us a measure of when, if at all, the model starts to predict changes in inflation expectations. If we find that the model fit increases after the break, we may conclude that expectations have become less anchored from that point on. Note that we adjusted the Chow test statistic so that we capture only the change in model performance due to news variables.[16]

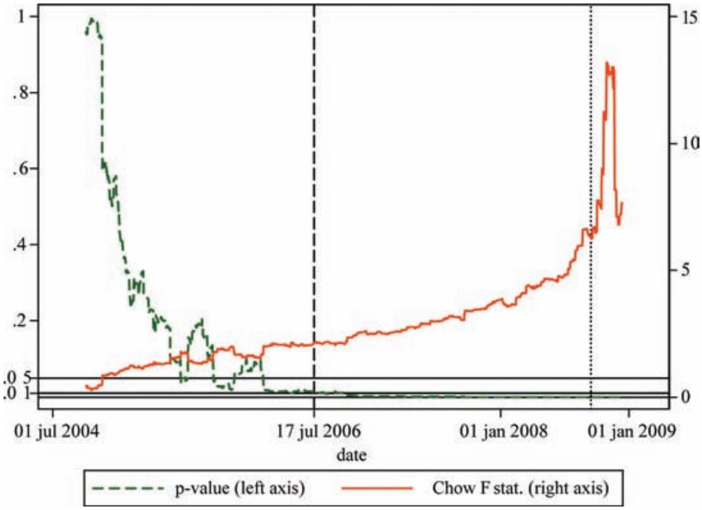
As a further step, we considered the most conservative dating of a structural break, given by the maximum of the test statistics from

[14]For reasons of space, the results for these dummies are not reported here. All variables used in the regressions are stationary.

[15]Note that the rolling Chow test does not rely on standard errors. Our analysis for the break dates is therefore unaffected by the choice between conventional OLS or heteroskedasticity-consistent standard errors (see footnote 13).

[16]If liquidity premia are important, then the implied volatility variables may also cause the Chow test to flag a break, just because volatility increased during the crisis period. To prevent this, we replaced the sum of squared residuals from the three regressions (entire period, before and after potential break point) in the test statistic with one minus their partial R-squared—where the explanatory effect of the control variables was partialled out—multiplied by their respective total sum of squares.

Figure 4. Chow Test Results for the United States



the rolling Chow tests (see Zeileis et al. 2003). We examined the change over time in both the F-test value and the p-value to assess the timing of a structural break.[17]

Our results—summarized separately for the United States, the euro area, and the United Kingdom in figures 4–6—indicate that the sensitivity of inflation expectations to news has indeed changed during the sample period. Each figure plots on the left axis the p-value of the Chow test for each day, and on the right axis the actual value of the test statistic. Several results stand out. First, the test statistics (and, inversely, the p-values) all increase toward end-2008 and early 2009, which coincides with the period of highest financial turmoil. The closer we get to the period of heightened financial stress—as highlighted by the dotted vertical line, the date at which Lehman Brothers filed bankruptcy—the more different the model performs in the later sample period compared with the first period. This indicates that in all three areas, the sensitivity of inflation expectations to macroeconomic news changed during the crisis.

[17] We truncate the sample by 100 observations on each side to allow for feasible testing near the beginning and end of the sample.

Figure 5. Chow Test Results for the Euro Area

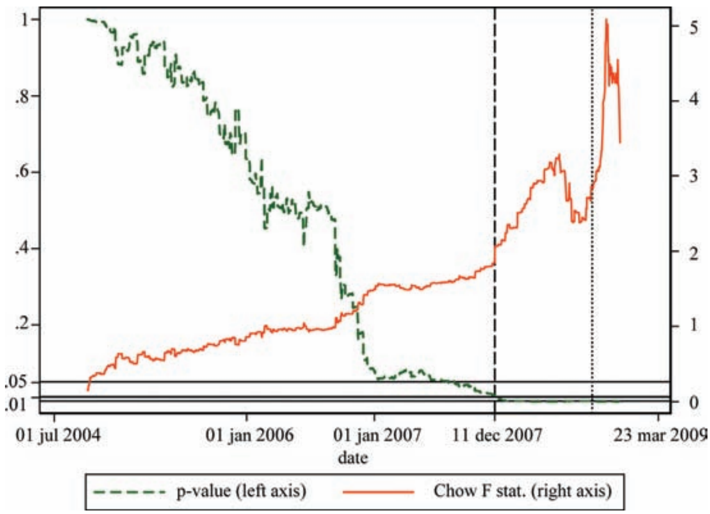
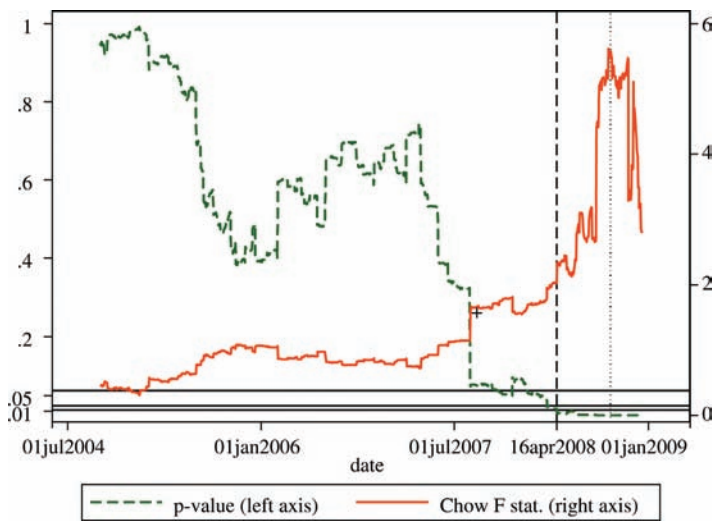


Figure 6. Chow Test Results for the United Kingdom



Secondly, we found a break in each economic area. The dates at which the Chow test becomes significant for the first time at the 99 percent confidence level are highlighted in the graphs by vertical dashed lines, and are reported in table 1. We identified a first

Table 1. Break Point Dating

		First Date Significant	**Maximum Test Value**
Euro Area	**Break Date**	**Dec. 11, 2007**	**Oct. 23, 2008**
	Chow F-test stat. p-value Andrews test stat. 1% critical value	2.064 0.005	5.081 7.95e-12 101.62 50.76
UK	**Break Date**	**April 16, 2008**	**Sep. 9, 2008**
	Chow F-test stat. p-value Andrews test stat. 1% critical value	2.302 0.005	5.615 4.93e-10 84.23 42.05
US	**Break Date**	**July 17, 2006**	**Oct. 30, 2008**
	Chow F-test stat. p-value Andrews test stat. 1% critical value	2.154 0.001	13.200 1.35e-27 184.8 401.0

Note: Regressions are run as specified in tables 2–4.

statistically significant change in the behavior of inflation expectations in July 2006 for the United States, in December 2007 for the euro area, and in April 2008 in the United Kingdom.

Thirdly, the test statistics show a hump-shaped pattern around the crisis period in all three economies, suggesting strong evidence for a break at the height of the crisis and decreasing evidence in the following months.

Table 1 shows, in addition to the timing of the first break identified by Chow tests, dates on which the Chow test statistic is maximized. Using this more conservative method of dating structural breaks in the relationship between inflation expectations and news, we find more similarities across the United States, the euro area, and the United Kingdom. For all three economies, the maximum Chow test statistic can be found between September and November of 2008, a period that is commonly considered the height of the financial crisis, and encompasses the collapse of Lehman Brothers on September 15, 2008.

As a robustness check, we used the method developed by Andrews (1993), which tests whether a structural break exists within a short period without knowing the break point.[18] The essence of these tests is to look at the test statistics yielded by Chow tests on each day within the period under consideration and construct new unified testing statistics from them. This helps to narrow down the location of the structural break. Once we identified the day on which the F-test statistic of our rolling Chow tests reaches its maximum, we applied the Andrews test to verify whether it identifies significant structural breaks around that day. The Andrews test indeed confirmed that at a 99 percent confidence level, a structural break exists on the days on which the Chow test statistics are maximized for all three economic areas.

Having identified structural breaks in the relationship between inflation expectations and inflation news and macroeconomic news, we looked at the fit of the model in each subsample to get evidence on whether inflation expectations became more or less anchored after those breaks. Since we are interested in the contribution of news on inflation and other macroeconomic variables, in this exercise we focus on the partial R^2 which excludes the effect of our measures of liquidity and technical factors. Tables 2–4 show the regression results for, respectively, the United States, the euro area, and the United Kingdom, and distinguish three different sample periods.[19] In each table, the first column refers to the entire sample period, while columns 2 and 3 report results for the subsamples before and after the day on which the Chow statistic reached its maximum.[20]

[18]See also Andrews and Ploberger (1994). Our approach is very similar to that used by Beechey and Wright (2008) to test for parameter instability.

[19]The results for the pre-crisis period are broadly consistent with the findings by Beechey, Johannsen, and Levin (forthcoming). The main difference is that we also find statistically significant effects on euro-area inflation expectations of news for France PPI, the German current account, Italian business confidence, and the Italian PPI. This difference is likely to come from the inclusion of the period July 31, 2003–March 23, 2004 in the Beechey, Johannsen, and Levin (forthcoming) regressions, and possibly from the different source of survey data on U.S. macro announcements—Beechey, Johannsen, and Levin (forthcoming) use Money Market Services, while we rely on Bloomberg.

[20]The results for the first significant break are available on request from the authors.

Table 2. Regression Results for the United States

	(1)	(2)	(3)
		Maximum Significance Oct. 30, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004–Mar. 23, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.033	0.032	0.289
Partial R^2	0.023	0.025	0.272
Adjusted Partial R^2	0.013	0.014	0.165
Observations	1189	1092	97
ISM Manufacturing PMI SA (value, NAPM)	0.55	1.42***	−6.33
	(0.68)	(0.54)	(4.63)
U.S. Personal Consumption Expenditure Core Price Index MoM SA	0.59	0.49	−1.71
	(0.77)	(0.59)	(8.18)
U.S. Capacity Utilization % of Total Capacity SA	1.98*	0.99	6.65
	(1.19)	(1.11)	(5.75)
Conference Board Consumer Confidence SA 1985=100	0.83	−0.58	7.86**
	(0.68)	(0.56)	(3.94)
U.S. Industrial Production MoM 2002=100 SA (rate)	−2.75**	−2.32*	−2.56
	(1.21)	(1.19)	(4.36)
U.S. Initial Jobless Claims SA	−0.95***	−0.14	−3.01**
	(0.33)	(0.29)	(1.45)
Conference Board U.S. Leading Index MoM	1.61**	−0.71	12.60***
	(0.68)	(0.56)	(3.71)
Federal Funds Target Rate	0.93	0.74	4.00
	(0.80)	(0.65)	(7.75)

(continued)

Table 2. (Continued)

	(1)	(2)	(3)
		Maximum Significance Oct. 30, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004– Mar. 23, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.033	0.032	0.289
Partial R^2	0.023	0.025	0.272
Adjusted Partial R^2	0.013	0.014	0.165
Observations	1189	1092	97
U.S. New Privately Owned Housing Units Started by Structure Total SAAR (units/thou)	−0.28	−0.47	−6.46
	(0.69)	(0.52)	(15.66)
U.S. Employees on Non-Farm Payrolls Total MoM Net Change SA (thousands)	0.08	0.54	−2.31
	(0.66)	(0.54)	(3.81)
Adj. Retail and Food Serv. SA Total Monthly % Change	1.38**	−1.35**	7.01**
	(0.69)	(0.63)	(2.74)
U.S. Unemployment Rate Total in Labor Force SA	−0.40	−0.81	2.32
	(0.70)	(0.57)	(4.29)
Δ Implied Volatility (Euro-Bund Future Continuous Call)	0.09	−0.00	0.47
	(0.15)	(0.12)	(0.86)
Δ VIX (CBOE SPX Volatility (New) – Price Index)	−0.47***	−0.37***	−0.43
	(0.15)	(0.14)	(0.62)
Constant	−0.00	0.05	−1.05
	(0.15)	(0.12)	(1.26)

Notes: The regression coefficients denote the impact of each news release measured in basis points. Standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 3. Regression Results for the Euro Area

	(1)	(2)	(3)
		Maximum Significance Oct. 23, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004–Mar. 12, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.028	0.076	0.231
Partial R^2	0.024	0.028	0.197
Adjusted Partial R^2	0.010	0.012	0.043
Observations	1232	1131	101
France Business Confidence Overall Indicator	0.12	−0.41	1.23
	(0.40)	(0.40)	(1.45)
France GDP QoQ	−0.64	−0.61	
	(0.68)	(0.54)	
France Industrial Production MoM SA 2000=100	−0.83**	−0.33	−3.95**
	(0.36)	(0.33)	(1.89)
France PPI MoM 2000=100	0.20	−0.34	0.45
	(0.38)	(0.67)	(0.95)
France Unemployment Rate SA	−0.00	−0.04	
	(0.42)	(0.33)	
France CPI MoM European Harmonized NSA	0.46	0.36	−2.52
	(0.37)	(0.29)	(6.88)
Bundesbank Germany Current Account EUR SA	−0.43	−0.64**	1.65
	(0.37)	(0.31)	(2.56)
Germany HICP MoN 2005=100	−0.11	−0.09	−3.88
	(0.41)	(0.33)	(6.23)
IFO Pan Germany Business Climate 2000=100	0.10	−0.11	1.21
	(0.38)	(0.33)	(2.11)
Germany Industrial Production MoM SA 2000=100	−0.10	0.41	−2.18
	(0.37)	(0.34)	(3.23)
Germany PPI MoM 1995=100	0.29	0.37	−1.38
	(0.36)	(0.33)	(1.59)

(continued)

Table 3. (Continued)

	(1)	(2)	(3)
		Maximum Significance Oct. 23, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004–Mar. 12, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.028	0.076	0.231
Partial R^2	0.024	0.028	0.197
Adjusted Partial R^2	0.010	0.012	0.043
Observations	1232	1131	101
Germany Unemployment Rate SA	−0.47	−0.22	−7.44*
	(0.36)	(0.29)	(4.04)
ZEW Germany Assessment of Current Situation	0.87**	1.02***	−1.14
	(0.38)	(0.31)	(4.56)
Italy Business Confidence 2000=100	0.08	−0.35	1.76
	(0.37)	(0.34)	(1.65)
Italy HICP MoM NSA 2005=100	0.25	0.03	3.55
	(0.38)	(0.30)	(3.50)
Italy Industrial Production MoM SA 2000=100	−0.16	−0.45	8.31*
	(0.35)	(0.29)	(4.50)
Italy PPI Manufacturing MoM 2000=100	1.37***	0.76**	3.49*
	(0.38)	(0.34)	(1.78)
Italy Real GDP QoQ SA WDA	−0.10	0.30	0.62
	(0.68)	(0.63)	(6.24)
Δ Implied Volatility (Euro-Bund Future Continuous Call)	0.04	−0.01	0.39
	(0.08)	(0.07)	(0.40)
Δ VIX (CBOE SPX Volatility (New) – Price Index)	−0.15*	−0.61***	0.77**
	(0.08)	(0.08)	(0.30)
Constant	−0.06	−0.03	0.19
	(0.08)	(0.07)	(0.70)

Notes: The regression coefficients denote the impact of each news release measured in basis points. Standard errors are in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4. Regression Results for the United Kingdom

	(1)	(2)	(3)
		Maximum Significance Sep. 9, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004– Mar. 24, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.023	0.028	0.111
Partial R^2	0.022	0.020	0.108
Adjusted Partial R^2	0.012	0.009	0.021
Observations	1204	1066	138
UK Manufacturing PMI Markit Survey Ticker	−0.28	−0.13	−0.57
	(0.45)	(0.39)	(1.59)
UK Industrial Production MoM SA	0.73**	0.38	2.50*
	(0.30)	(0.25)	(1.38)
UK CPI EU Harmonized MoM NSA	0.87*	0.39	1.80
	(0.48)	(0.42)	(1.72)
UK Retail Prices Index MoM NSA	−0.04	−0.19	2.51
	(0.48)	(0.38)	(2.65)
UK Nationwide Consumer Confidence Index SA	2.81***	−4.69***	5.73**
	(1.07)	(1.42)	(2.86)
UK Unemployment Claimant Count Monthly Change SA	−0.52	−0.32	0.03
	(0.42)	(0.35)	(1.80)
UK Claimant Count (Unemployment) Rate SA	−0.03	0.46	−1.66
	(0.43)	(0.33)	(2.25)
BoE Official Bank Rate	−0.52	−1.03	−0.55
	(0.35)	(0.64)	(0.88)

(continued)

Table 4. (Continued)

	(1)	(2)	(3)
		Maximum Significance Sep. 9, 2008	
Break Date (99% Confidence Level):	**Jun. 23, 2004– Mar. 24, 2009**	**Pre-Break**	**Post-Break**
Overall R^2	0.023	0.028	0.111
Partial R^2	0.022	0.020	0.108
Adjusted Partial R^2	0.012	0.009	0.021
Observations	1204	1066	138
UK Chained GDP at Market Prices QoQ	0.58	0.20	1.86
	(0.60)	(0.45)	(2.94)
UK Retail Sales All Retailing	0.46	0.09	1.99
	(0.34)	(0.26)	(1.77)
UK PPI Manufactured Products M	−0.08	−0.41*	4.37
	(0.35)	(0.25)	(2.81)
UK Avg. Earnings Whole Economy	−0.12	−0.01	−0.66
	(0.36)	(0.32)	(1.25)
Δ Implied Volatility (Euro-Bund Future Continuous Call)	0.07	0.11*	0.11
	(0.08)	(0.06)	(0.37)
Δ VIX (CBOE SPX Volatility (New) – Price Index)	−0.02	−0.20**	0.02
	(0.08)	(0.09)	(0.23)
Constant	0.04	0.12**	−0.58
	(0.08)	(0.05)	(0.56)

Notes: The regression coefficients denote the impact of each news release measured in basis points. Standard errors are in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The tables highlight that in all three economic areas, the sensitivity of inflation expectations increased in the run-up to and during the crisis. In particular, the reaction of inflation expectations to news on U.S. inflation was much higher in July 2006–March 2009 than in June 2004–July 2006.[21] The partial R^2, which captures the explanatory power of news on inflation and other macroeconomic variables, increased from 1.9 percent to 5.1 percent between the first and the second subsample. In the euro area, the partial R^2 rose to 6.4 percent in the period December 2007–March 2009, from 2.9 percent during the period June 2004–December 2007. The difference is even starker in the United Kingdom: the partial R^2 increased almost sixfold, from 1 percent to 5.7 percent.

The change in model fit over time is even more evident when we split the sample period on the dates on which the Chow test statistics are maximized (columns 2 and 3 in tables 2–4). The increase in model performance—measured by the partial R^2—is most visible for the United States, where economic news explained only 2.5 percent of the changes in inflation expectations before October 30, 2008 but 27.2 percent of the variation after that date! The partial R^2 surged also in the regressions for the euro area, from 2.8 percent before October 23, 2008 to 19.7 percent after. The model fit also increases from 2 percent to 11.0 percent for the United Kingdom. Note that the number of observations is lower in the post-break period than in the pre-break period, and hence the increase in the partial R^2 after the break could result from an overfitting problem and has to be read with caution. However, a comparison of the adjusted R^2, which takes the different number of observations into account, across subsamples confirms a better fit in the post-break period.[22]

[21]For the euro area and the United Kingdom, these results are not sensitive to the presence of outliers, which is noteworthy since surprises in macro data releases tend to have heavy-tailed distributions. For the United States, excluding four outliers causes the partial R^2 to no longer increase after the first break, although the partial R^2 does increase substantially after the maximum break. We conclude that for the United States, outliers have some influence on the results of break tests, but they do not drive the main results.

[22]The adjusted R^2 is reported in tables 2 to 4. As a robustness check, we also looked at a pre-break period with exactly the same amount of observations as the post-break period. We found again that the model fits the data better after than before the break.

These results could be interpreted as a warning sign that around the end of 2008, and probably earlier, long-run inflation expectations might have started to be less perfectly anchored in all three economies. However, a closer look at the news variables that have explanatory power for changes in inflation expectations reveals an important difference between the euro area and the United Kingdom on one hand, and the United States on the other. In the euro area and the United Kingdom, no economic data releases were significant at the 99 percent confidence level and only one was significant at the 95 percent level. This suggests that during the crisis, forward inflation compensation in these economies was not particularly sensitive to economic news. Hence, from that viewpoint, inflation expectations in the euro area and the United Kingdom should still be viewed as having remained relatively well anchored. By contrast, the U.S. forward inflation compensation was just as sensitive to particular macroeconomic news variables during the crisis as it had been prior to the crisis, providing further evidence that inflation expectations may not have been as firmly anchored in the United States as in the euro area or the United Kingdom.

To get a sense of the magnitude of the sensitivity of inflation expectations to news, we compared our results with those reported by Gürkaynak et al. (2006) and Gürkaynak, Levin, and Swanson (2010) for the United Kingdom and United States for data up to 2005.[23] They found that economic news was able to explain 4 percent of the variation of U.S. inflation compensation between 1998 and 2005.[24] The results in table 3 suggest that the sensitivity of inflation expectations to news increased significantly during the crisis. The same holds for the United Kingdom. Gürkaynak, Levin, and Swanson (2010) report that after the Bank of England became independent, economic news only explained up to 3 percent of the variation in inflation compensation (between 1998 and 2005).[25] We found that after September 2008 our model fit rose to 10.9 percent, which lies about halfway between our model fit for the pre-crisis

[23]Beechey, Johannsen, and Levin (forthcoming) do not report measures of model fit, so we could not compare what we found to their results.

[24]This includes the statistically significant effect of several first-business-day-of-the-year dummies, which we did not include in our regressions.

[25]The explanatory power is not higher when international macro news was also included.

years (2004–06) and the model fit that Gürkaynak et al. (2006) found for the period before the Bank of England gained independence (1993–97).

6. Conclusions

To what extent have inflation expectations been affected by the economic crisis that erupted in mid-2007? In particular, have anchoring properties of long-run inflation expectations changed as the crisis unfolded? In our paper we addressed these questions by examining long-run inflation expectations in the United States, the euro area, and the United Kingdom between June 2004 and March 2009. We considered two types of measures of long-run inflation expectations: survey-based measures and measures extracted from inflation-linked financial market instruments.

In the period 2004–09, the dynamics of survey-based measures of long-run inflation expectations differed across the three economies. They remained fairly stable within the ECB's comfort zone in the euro area, fluctuated above 2 percent in the United States, and drifted up in the United Kingdom. In addition, the cross-sectional dispersion of survey-based measures rose markedly in the United States and the United Kingdom.

Expectations measures extracted from inflation-indexed bonds and inflation swaps show a marked increase in volatility since 2007. Moreover, we found evidence that their sensitivity to news about inflation and other domestic macroeconomic variables has increased since 2006. The reactivity to news increased particularly during the period of heightened turmoil triggered by the collapse of Lehman Brothers in September 2008, when central banks significantly eased monetary policy using both standard and non-conventional tools.

Although it has been argued that liquidity premia and technical factors have significantly influenced the behavior of inflation-indexed markets since the onset of the crisis, we found that they did not contaminate the relationship between macroeconomic news and financial market-based inflation expectations at the daily frequency.

While our graphical evidence on survey-based measures of inflation expectations does not allow definitive conclusions on the anchoring of expectations during the crisis, it is consistent with the idea that long-term expectations may have become somewhat less firmly anchored in the United States and the United Kingdom. Similarly, our results on financial market-based expectations measures have to be interpreted with great caution given that our understanding of day-to-day changes in financial markets remains far from perfect and shifts in liquidity are not easily distinguishable from shifts in long-run inflation expectations or perceived inflation risk. With these caveats in mind, our evidence on structural breaks suggests that in the United States, the euro area, and the United Kingdom, long-run inflation expectations may have become less firmly anchored during the crisis. However, in the euro area and the United Kingdom, there are no economic data releases that are highly statistically or economically significant during the crisis, suggesting that from that viewpoint, inflation expectations should be viewed as having remained relatively well anchored. In contrast, our evidence indicates that in both subsamples, some macroeconomic news variables are highly significant for U.S. forward inflation compensation, providing further evidence that inflation expectations may not have been as firmly anchored in the United States as in the euro area or the United Kingdom.

One interpretation of our results is that at the height of the crisis, market participants viewed monetary authorities as focusing mainly on fixing the monetary transmission mechanism and on softening the impact of financial instability on the real economy. This appears to have affected market participants' views on the commitment of central banks to fighting inflation. In the midst of a crisis, this seemed less of a problem given the absence of inflationary pressures. However, once the economy regains traction, central banks need to carefully devise exit strategies from their expansionary monetary stance.

Whether the extent to which anchoring properties have changed during the crisis depends on monetary frameworks—such as an inflation-targeting regime—or the strategies that were followed to counter the impact of the crisis, is an important topic for future research. In terms of methodology, we conclude that the approach developed by Gürkaynak, Sack, and Swanson (2005) and others is flexible enough to be used to investigate the properties of expectations during crisis times.

Differences between the dynamics of survey-based measures and those of measures based on financial instruments may at least in part stem from difficulties in measuring expectations accurately. They could also reflect important heterogeneities in the expectation formation mechanism across different types of agents. Understanding these differences and their implications for policymakers is an important avenue for future research.

Appendix 1. The Nelson-Siegel Method

There is an extensive literature on modeling the term structure of interest rates or inflation swap rates. The seminal paper by Nelson and Siegel (1987) proposes a three-factor model that captures the level, slope, and curvature of the yield curve. Empirical studies shows that it fits well for yield curves with different shapes.[26] At each time point t, the model is given as follows:

$$y_t^{(m)} = \beta_{1,t} + \beta_{2,t}\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) + \varepsilon_t^{(m)}. \tag{4}$$

Here $y_t^{(m)}$ is the yield with maturity m; $(\beta_{1,t}, \beta_{2,t}, \beta_{3,t})$ is the vector of parameters for the three factors, which indicate level, slope, and curvature of the yield curve; λ is a decay parameter, which is usually assumed to be constant across time; and $\varepsilon_t^{(m)}$ is an error term.

To estimate this model is by no means an easy task. In particular, taking the dynamics of the beta parameters into account always involves advanced techniques such as a Kalman filter (see Diebold, Rudebusch, and Aruoba 2006). However, by fixing the decay parameter λ, the estimation becomes a simple OLS regression. An example of this approach is in Diebold and Li (2006).

We did not choose a particular value for the decay parameter ex ante. Rather, we allowed the decay parameter to vary on a certain interval, while estimating the Nelson-Siegel model for each specific value in this interval. We then chose the value of the decay parameter at which the total mean squared error is minimized.

[26]For a recent discussion of the empirical performance of the Nelson-Siegel method, see, e.g., de Pooter (2007).

When estimating the Nelson-Siegel model for a specific value of λ, the observations are the yields at different maturities. In our data set, the available maturities are one, two, three, four, five, six, seven, eight, nine, ten, twelve, fifteen, twenty, and thirty years. The observations are therefore concentrated at the shorter end of the yield curve, making it more difficult to accurately represent the shape of the yield curve at longer maturities. In order to balance this effect, we introduced other maturities—such as eleven, thirteen, fourteen, sixteen, seventeen, eighteen, nineteen, twenty-one, and twenty-two years. To obtain yields on those maturities, we used the bootstrapping method in Fama and Bliss (1987).

We followed this procedure to estimate the yield curves for inflation swaps and interest rate swaps for each day t. Based on the estimated yield curve for inflation swaps, we obtained the yield with nine- and ten-year maturities. These were used to calculate the ten-year-ahead forward rates.

Appendix 2. Macroeconomic Data Releases

United States

- ISM Manufacturing PMI SA (value; NAPM)
- Personal Consumption Exp. CPI MoM SA
- Capacity Utilization % of Total Capacity SA
- Conference Board Consumer Confidence SA
- Industrial Production MoM SA (rate)
- Initial Jobless Claims SA
- Conference Board US Leading Index MoM
- Federal Funds Target Rate
- New Privately Owned Housing Units Started by Structure Total SAAR
- Employees on Non-Farm Payrolls MoM SA
- Adjusted Retail & Food Services SA MoM
- Unemployment Rate Total in Labor Force SA

United Kingdom

- Manufacturing PMI Markit Survey Ticker
- Industrial Production MoM SA
- CPI EU Harmonized MoM NSA
- Retail Prices Index MoM NSA

Nationwide Consumer Confidence Index
Unemployment Claimant Count MoM SA
Claimant Count (Unemployment) Rate SA
BoE Official Bank Rate
Chained GDP at Market Prices QoQ
Retail Sales All Retailing
PPI Manufactured Products M
Avg. Earnings Whole Economy

Euro Area

France
France Business Confidence Overall Indicator
France GDP QoQ
France Industrial Production MoM SA 2000=100
France PPI MoM 2000=100
France Unemployment Rate SA
France CPI MoM European Harmonized NSA

Germany
Germany Current Account EUR SA
Germany HICP MoN 2005=100
IFO Pan Germany Business Climate 2000=100
Germany Industrial Production MoM SA 2000=100
Germany PPI MoM 1995=100
Germany Unemployment Rate SA

Italy
Business Confidence 2000=100
Italy HICP MoM NSA 2005=100
Italy Industrial Production MoM SA 2000=100
Italy PPI Manufacturing MoM 2000=100
Italy Real GDP QoQ SA WDA

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Discussion of "Did the Crisis Affect Inflation Expectations?"*

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1. Introduction

As is currently well recognized, anchoring long-term inflation expectations is a key to successful monetary policy. Chen Zhou and his coauthors, Gabriele Galati and Steven Poelhekke (Galati, Poelhekke, and Zhou 2011, hereafter GPZ) address an important current policy question: did the crisis affect long-term inflation expectations?

To address the above question, GPZ carry out an econometric analysis using high-frequency market-based indicators for long-term inflation expectations in the United States, the euro area, and the United Kingdom. They find that long-term inflation expectations have become more responsive to macroeconomic news, suggesting the possibility of less firmly anchored inflation expectations after the crisis.

GPZ's efforts to employ high-frequency market data to assess whether long-term inflation expectations are firmly anchored after the financial crisis are important trials, which can be viewed as a real-time assessment of policy performance. Unfortunately, however, GPZ's empirical results are still inconclusive because of noisy market data under destabilized financial markets during the financial crisis. It is thus deemed necessary to reformulate their empirical strategy to obtain robust conclusions even in times of crisis. I will elaborate on those points in my comments below.

 The views expressed here are mine and do not necessarily reflect the official position of the Bank of Japan. I thank Hiroyuki Ooi and Kentaro Koyama for their assistance.

2. Empirical Framework

My first comment concerns the empirical framework used in GPZ. Following Gürkaynak, Sack, and Swanson (2005), GPZ employs the specification below that regresses measures of long-term inflation expectations on a constant term, a set of explanatory variables, and a set of control variables:

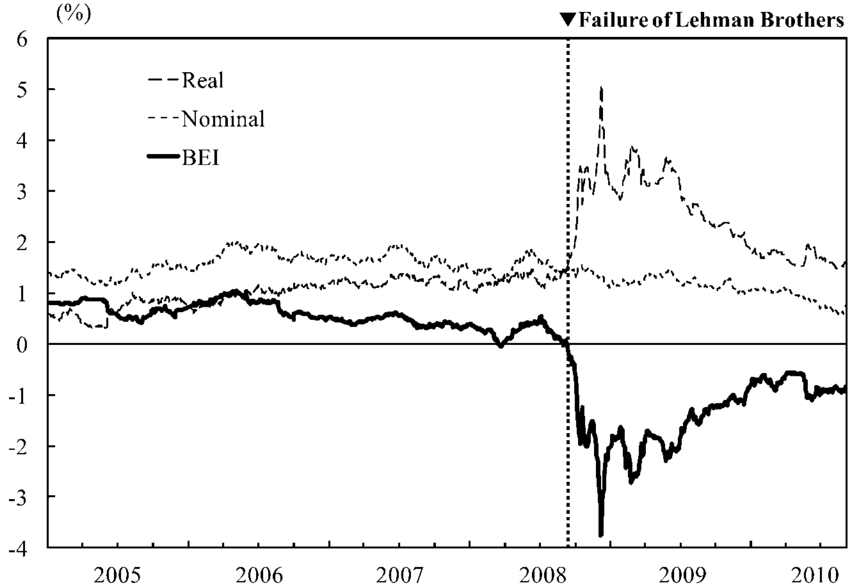
$$\Delta f_t = \alpha + \beta \mathbf{X}_t + \gamma \mathbf{Z}_t + \varepsilon_t, \tag{1}$$

where the dependent variable Δf_t is the daily change in one-year inflation compensation ten years ahead. The explanatory variables $\mathbf{X}_t$ are a vector of news variables on various measures of the state of the economy, defined as differences between actual release and ex ante survey data. $\mathbf{Z}_t$ is a vector of control variables intended to capture the changes in market conditions, especially shorter-term fluctuations of market liquidity and technical factors unrelated to inflation expectations.

Two points should be noted in the above specification. First, it is crucially important to control for relative changes in market conditions in nominal and inflation-indexed government bond markets to obtain robust empirical results. I am concerned about how effectively this paper does that. As shown in GPZ, estimates of the control variables become less statistically significant, and some of them have the wrong sign after the crisis. The empirical results in GPZ suggest that it is difficult to control for relative changes in market conditions in nominal and inflation-indexed government bond markets simply by using VIXs or implied volatility of stock price indexes, especially under stressed conditions in financial markets.

Second, assuming that fluctuations in market liquidity and other technical factors are adjusted adequately by the control variables, the explanatory variables are expected to be insignificant if inflation expectations are firmly anchored. However, it seems quite difficult to control for fluctuations in market liquidity and other technical factors under highly stressed market conditions. It thus does not seem robust enough to empirically examine only the irresponsiveness of market-based indicators for long-term inflation expectations to macroeconomic news. In that sense, it should be noted that that line of hypothesis testing provides only a necessary condition and not a sufficient condition to assess whether long-term inflation expectations are anchored. It is thus deemed appropriate to consider that

Figure 1. Break-Even Inflation Rates in Japen



Source: Bloomberg.

the empirical framework of GPZ is applicable only to normal times and not to crisis times.

To examine the effects of highly stressed market conditions after the failure of Lehman Brothers in September 2008, figure 1 plots yields on nominal and inflation-indexed government bonds as well as break-even inflation rates in Japan. After the failure of Lehman Brothers, yields on nominal and inflation-indexed government bonds decoupled and became exceptionally volatile.[1,2] The yields on

[1]Campbell, Shiller, and Viceira (2009) point out that a similar phenomenon of decoupling of the yields on nominal and inflation-indexed government bonds is also observed in the United States after the failure of Lehman Brothers in September 2008.

[2]Inflation-indexed government bonds issued in Japan and the United Kingdom are adjusted for the principal in a symmetric manner to inflation and deflation, thereby guaranteeing the real value of the principal. By contrast, inflation-indexed government bonds issued in the United States are adjusted in an asymmetric manner so as to guarantee the face value of the principal. That gives U.S. inflation-indexed government bonds an option-like feature when deflation is anticipated.

inflation-indexed government bonds rose sharply to a higher level than nominal government bonds, making the break-even inflation rate negative.

The above observation suggests two possibilities: one is heightened deflationary expectations, and the other is a sudden and significant decline in market liquidity in the inflation-indexed bond market relative to the nominal bond market. Sudden and sharp increases in the yields of inflation-indexed government bonds, while gradually declining the yields of nominal government bonds, indicate that the second possibility is more likely to be provoked by segmented markets with unexploited arbitrage opportunities between nominal and inflation-indexed government bonds markets due to tightened liquidity constraints at highly leveraged financial institutions.[3]

3. The Use of the Nelson-Siegel Model

My second comment relates to the use of Nelson and Siegel's (1987) model. The Nelson-Siegel model specifies the instantaneous forward rate (IFR) for a settlement at period m, denoted by $r(m)$, as

$$r(m) = \beta_0 + \beta_1 \cdot \exp\left(-\frac{m}{\tau}\right) + \beta_2 \cdot \left(\frac{m}{\tau}\right) \cdot \exp\left(-\frac{m}{\tau}\right), \qquad (2)$$

where β_0, β_1, β_2, β_3, and τ are parameters to be estimated from the data, and β_0 and τ are expected to be positive.

The above model has simple, parsimonious functional forms but is flexible enough to capture the general properties of the yield curve for monetary policy purposes. In that regard, important features of equation (2) are that the limits of forward and spot rates when maturity approaches zero and infinity, respectively, are equal to $\beta_0 + \beta_1$ and β_0. In the estimation procedure, those features are very convenient for avoiding the very short end of the IFR curve becoming negative, by restricting that the overnight rate is equal to $\beta_0 + \beta_1$.[4]

[3] Saito and Shiratsuka (2001) examine Japan's financial crisis in the late 1990s from the viewpoint of the failure of arbitrage between financial markets.

[4] Okina and Shiratsuka (2004) show that the yield curve can be estimated with tight confidence intervals even under the zero lower bound of short-term nominal interest rates, by using the extended version of the Nelson-Siegel model, proposed by Söderlind and Svensson (1997). The extended Nelson-Siegel model allows up to two humps or U shapes in the IFR curve, while the original one has only one hump or U shape.

In addition, it is important to note that confidence intervals for the estimated coefficients can be computed from their standard errors.

With the estimates of the Nelson-Siegel model, GPZ compute one-year forward rates ending ten years ahead as a market-based indicator for long-term inflation expectations, $f_{t,10}$, using equation (3) below:

$$f_{t,10} = (1 + y_{10})^{10}/(1 + y_9)^9 - 1, \tag{3}$$

where y_9 and y_{10} are spot rates with maturity of nine and ten years, respectively.

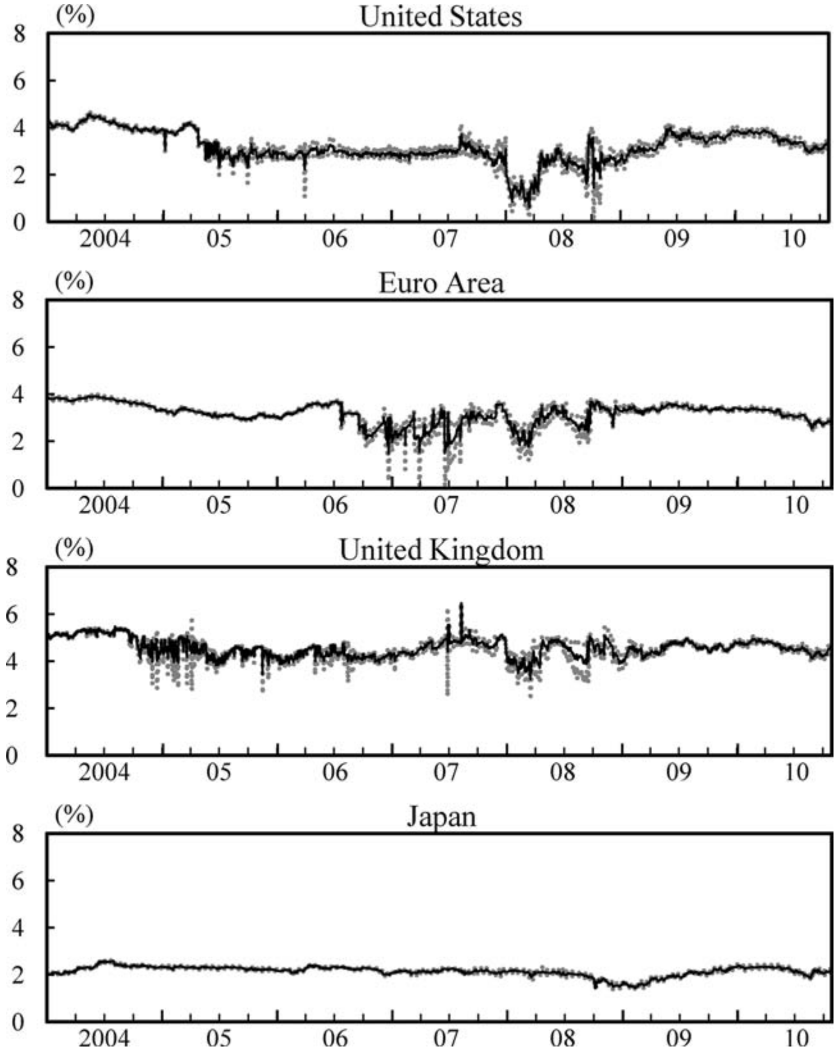
However, the above definition of the explanatory variables does not make full use of the convenient properties of the Nelson-Siegel model. I suggest using an alternative indicator of β_0, or long-term forward rate, based on the estimates of the Nelson-Siegel model. That indicator corresponds to inflation expectations at an infinite horizon, and thus seems to be more appropriate from the viewpoint of tracing long-term inflation expectations. At the same time, it becomes more informative by computing confidence intervals for the estimates of β_0, with its estimated standard errors.

In addition, market data for inflation swaps and inflation-indexed government bonds are available for a wide range of maturities, thus enabling us to compute the term structure of inflation expectations. With such data, it seems interesting to analyze dynamics of term structure of inflation expectations and their responses to macroeconomic news at different maturities.

In order to seek a direction of future extensions of the paper, figure 2 plots the estimates of β_0, or long-term forward rates for the United States, the euro area, the United Kingdom, and Japan.[5] The figure shows that long-term forward rates in Japan move in a fairly stable manner at a relatively low level. In particular, long-term forward rates in Japan do not show volatile fluctuations even during the financial crisis, in contrast to the other three economies. That point is confirmed by the tight confidence intervals in Japan, compared with the other three economies.

[5] In estimating β_0, I use the extended Nelson-Siegel model as well as market interest rate data for overnight policy rates, LIBORs for one to twelve months, and swap rates for one year and longer.

Figure 2. Long-Term Forward Rates



Source: Author's calculation.
Note: Solid lines are estimated coefficients, and shaded and dotted lines indicate their upper and lower bounds, respectively, of the confidence interval (estimated coefficients ± two standard errors).

4. Conclusions

In closing, I emphasize the importance of conducting further research work for examining long-term inflation expectations using high-frequency market data. GPZ show that the high-frequency market data analysis is an effective analytical tool to assess monetary policy performance, even though their empirical results are still inconclusive because of noisy market data under destabilized financial markets during the financial crisis.

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Some Methodological Suggestions

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Methodological suggestions are made for two separate issues. First, I show how a consistent estimate of the *level* of the expected inflation can be gleaned from inflation swap rates. Second, I indicate how the dynamic general equilibrium model in question can be modified to generate the observed persistence in commodity price movements.

JEL Codes: E52, G13, Q43.

1. Introduction

Rather than providing a big picture about monetary policy, I appoint myself as a discussant of the two papers presented in this session, one on inflationary expectations by Galati, Poelhekke, and Zhou, and the other on the recent commodity boom by Erceg, Guerrieri, and Kamin. For each of the two papers, which I take to be the best industry practice, I will suggest an alternative methodology. My commentary is almost self-contained; the reader should be able to get the main messages without reference to the two underlying papers.

2. How to Estimate the *Level* of the Expected Inflation Rate

The Galati, Poelhekke, and Zhou paper examines the inflation expectations that can be inferred from financial markets. There are two sources: inflation-indexed bonds and inflation swaps. The methodological challenge is to disentangle the risk premium from expectations. I will focus on inflation swaps rather than on indexed bonds because my methodological suggestion can be stated more cleanly for the former.

A zero-coupon inflation swap, which is a promise to exchange the value proportional to the level of the CPI (consumer price index) at maturity for an amount agreed upon today and which involves no exchange of cash flows until maturity, is a futures contract. Since swaps for different maturities are traded, one can construct, much as we do routinely for bonds, the constant-maturity "yield curve" for inflationary expectations. For example, say today's date is September 16, 2010, and say two different kinds of contracts are traded: those for the end of August 2020 delivery and those for the end of September 2020 delivery. One can construct a measure of the expected inflation rate over the next ten years from an average of the August 2020 swap rate and the September 2020 rate. Therefore, in what follows I can proceed as if swap/futures contracts are like forward contracts in that prices are available for any given maturity at any date.

Having noted an analogy between swaps and futures, let me provide a refresher on the language of futures markets. I do this because things routinely done in the futures/forward market literature will turn out to be useful in the context of inflationary expectations. Let S_t be the spot price on date t and $F_{t,M}$ be the futures price on date t for delivery M periods hence, on date $t+M$ (as just argued, we can pretend that for any given maturity M there are futures contracts traded on date t). The *excess return*, the *risk premium*, and the *basis* are defined as

$$\text{(Excess Return)} \qquad ER_{t,t+M} \equiv \frac{(S_{t+M} - F_{t,M})/F_{t,M}}{M}, \tag{1}$$

$$\text{(Risk Premium)} \qquad RP_{t,M} \equiv \mathrm{E}_t(ER_{t,t+M}), \tag{2}$$

$$\text{(Basis)} \qquad Basis_{t,M} \equiv \frac{(S_t - F_{t,M})/F_{t,M}}{M}, \tag{3}$$

where, as usual, E_t is the expectations operator conditional on information available at t. The deflation by M is for stating the quantities per unit of time. Equation (1) defines the return from taking a long position in the futures market, expressed as a fraction of the notional $F_{t,M}$. It is an excess return because taking a position requires no cash. Equation (2) shows that the ex post risk premium is the excess return.

Using the log-linear approximation (that $\log(1 + x) \approx x$) and writing natural logs in lowercase letters (e.g., $s_t \equiv \log(S_t)$), we can derive the following equations:

$$\text{(Excess Return)} \quad ER_{t,t+M} = \frac{1}{M}(s_{t+M} - f_{t,M}), \tag{4}$$

$$\text{(Risk Premium)} \quad \frac{1}{M}\mathrm{E}_t(s_{t+M}) = \frac{1}{M}f_{t,M} + RP_{t,M}, \tag{5}$$

$$\text{(Basis)} \quad Basis_{t,M} = \frac{1}{M}(s_t - f_{t,M}), \tag{6}$$

$$\text{(ER Decomposition)} \quad ER_{t,t+M} = \frac{1}{M}[s_{t+M} - \mathrm{E}_t(s_{t+M})] + RP_{t,M}. \tag{7}$$

The last equation, equation (7), can be derived by eliminating $f_{t,M}$ from (4) and (5). Equation (5) emphasizes that the expected price differs from the futures price by the risk premium. In the context of foreign exchange forward contracts, s_t is the spot exchange rate and $f_{t,M}$ is the M-period forward rate, so the forward premium (the difference between the spot and forward exchange rates) is the basis.

The familiar efficient market hypothesis for foreign exchange markets is that the expected spot rate equals the forward rate, namely that the risk premium is zero. As the large literature on the forward premium puzzle shows, the existence of the risk premium has long been suspected for the foreign exchange markets. Recent work on other markets reports that the risk premium is sizable in commodity futures (Gorton and Rouwenhorst 2006) and in emerging-market currencies (Gilmore and Hayashi 2008).

The risk premium is also suspected to be time dependent because it appears to be related to observable variables. A standard way to document this is to run the *excess return regression* in which the ex post risk premium, which is the excess return, is regressed on the basis:

$$ER_{t,t+M} = \alpha + \beta Basis_{t,M} + \text{error}. \tag{8}$$

This is a very familiar regression in disguise. Substituting (4) and (6) into this regression and rearranging, one obtains

$$\frac{1}{M}(s_{t+M} - s_t) = \alpha + (1-\beta)\left(\frac{1}{M}(f_{t,M} - s_t)\right) + \text{error}. \tag{9}$$

This is none other than the "Fama regression" in the forward premium puzzle literature: the dependent variable is the spot return and the regressor is the forward premium. The forward premium puzzle is that typically the coefficient $1-\beta$ in the Fama regression is *negative* and sometimes less than -1, implying that the basis coefficient in the excess return regression is far greater than unity.

Getting back to the equivalence between zero-coupon inflation swaps and futures, set $S_{t+M} = CPI_{t+M}/CPI_t$ (where CPI_t is the level of the CPI at t) and define $y_{t,M}$ by the relation $\exp(y_{t,M}M) = F_{t,M}$ (i.e., $y_{t,M} \equiv \frac{1}{M} f_{t,M}$). This $y_{t,M}$, called the *break-even inflation rate* over M periods, is the expected inflation measure one can infer from swaps. The four equations, (4)–(7), can be written as

$$ER_{t,t+M} = \underbrace{\frac{1}{M}[\log(CPI_{t+M}) - \log(CPI_t)]}_{\text{actual inflation over } M \text{ years}} - y_{t,M}, \tag{10}$$

$$\underbrace{\mathrm{E}_t\left[\frac{1}{M}(\log(CPI_{t+M}) - \log(CPI_t))\right]}_{\text{expected inflation rate over } M \text{ years}} = y_{t,M} + RP_{t,M}, \tag{11}$$

$$Basis_{t,M} = -y_{t,M}, \tag{12}$$

$$ER_{t,t+M} = \underbrace{\frac{1}{M}[\log(CPI_{t+M}) - \mathrm{E}_t(\log(CPI_{t+M}))]}_{\text{unexpected inflation over } M \text{ years}} + RP_{t,M}. \tag{13}$$

Equation (10) shows how the excess return is calculated from data on the CPI and the break-even inflation rate. That the expected inflation measure (i.e., the break-even inflation rate) differs from the true expected inflation by the risk premium is emphasized this time by (11). Equation (12) shows that (the negative of) the break-even inflation rate is the basis.

The Galati, Poelhekke, and Zhou paper assumes that the change in the risk premium is a linear function of a vector of observable variables, denoted $\mathbf{Z}_t$. Here, I assume that the *level* of the risk premium is a linear function of $\mathbf{Z}_t$:

$$RP_{t,M} = \boldsymbol{\gamma}'\mathbf{Z}_t. \tag{14}$$

Substituting this into (13) and denoting the first term on the right-hand side of (13), which is an expectation error, by $\varepsilon_{t,t+M}$, we obtain the following excess return regression:

$$ER_{t,t+M} = \boldsymbol{\gamma}'\mathbf{Z}_t + \varepsilon_{t,t+M}, \quad t = 1, 2, \ldots, T - M, \tag{15}$$

where T is the sample size and M (recall) is the maturity. By definition, the error term $\varepsilon_{t,t+M}$ is orthogonal to the regressor $\mathbf{Z}_t$ under rational expectations. Therefore, the coefficient $\boldsymbol{\gamma}$ can be consistently estimated by OLS (ordinary least squares).

The alternative methodology I suggest, then, is the following:

(i) Estimate the coefficient $\boldsymbol{\gamma}$ in the excess return regression (15) by OLS. This produces a consistent estimate $\hat{\boldsymbol{\gamma}}'\mathbf{Z}_t$ of the risk premium $RP_{t,M}$ where $\hat{\boldsymbol{\gamma}}$ is the OLS coefficient estimate. Given the prominence of the basis in the commodity futures and foreign exchange literature, the control variables $\mathbf{Z}_t$ should include the break-even inflation rate (i.e., the basis).

(ii) Calculate the *level* of the expected inflation rate (the left-hand side of (11)) as $y_{t,M} + \hat{\boldsymbol{\gamma}}'\mathbf{Z}_t$.

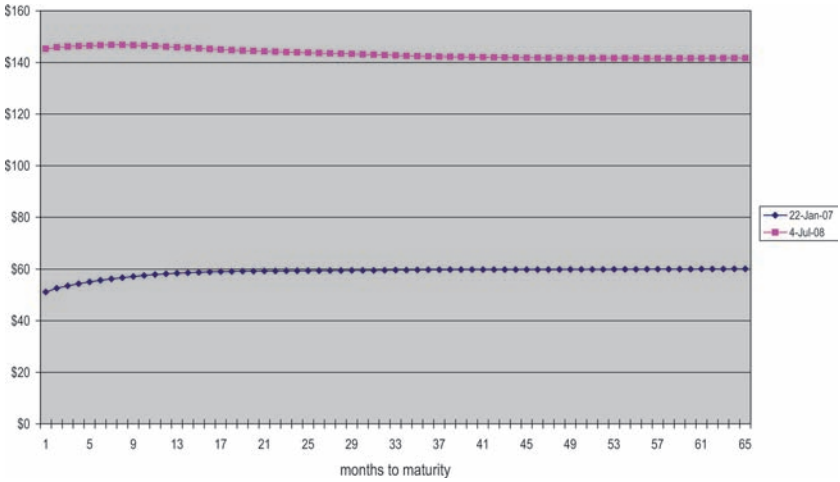
3. Accounting for the Persistence in Commodity Prices

I now turn to the paper by Erceg, Guerrieri, and Kamin on the recent run-up in commodity prices. My suggestion is to introduce inventories in the dynamic general equilibrium model used in the paper. The reason for my suggestion is that commodity prices exhibit persistent movements and inventories can account for that.

The persistence of commodity prices is apparent from the paper's figure 1, which plots the "spot" price of WTI (West Texas Intermediate) oil (I assume the "spot" price here is measured by the futures price of the nearest contracts, which is legitimate because futures prices converge to spot prices as the maturity approaches zero). Indeed, if one takes the monthly series on the WTI nearest futures price and regresses the log of the current price on the last month's log price, one gets a coefficient of 0.99. The oil price behaves like a random walk.

The market seems to have noticed the near random walk behavior of commodity prices. Looking at the paper's plot of the spot oil price, one notices the run-up stretching from \$51 on January 22, 2007 to \$145 on July 4, 2008, followed by the plunge to below \$40. This commentary's figure 1 shows the WTI forward curve (the plot of the WTI futures price against months to maturity for any given date)

Figure 1. WTI Forward Curves



on January 22, 2007 and July 4, 2008. Clearly, the market believed that the price would remain more or less the same. In particular, the market didn't anticipate the plunge after July 2008.

There is a well-established theory of commodity prices in Deaton and Laroque (1992). They assume risk-neutral inventory holders who enforce the usual arbitrage condition linking the current spot price to the expected future spot price. The arbitrage condition holds with equality when the level of inventory is positive. In the event of a stockout, the current spot price shoots up to equate demand to current output of the commodity. Their model can account for the near random walk behavior and occasional run-ups of the spot price. Although their model, with an exogenously given demand curve and with output assumed to be an exogenous endowment process, is partial equilibrium in nature, it should be feasible to introduce inventory holders into the dynamic general equilibrium model. It seems to me that all that is required is to add the inventory arbitrage condition and modify the market equilibrium condition for the commodity by adding the change in inventory to the amount supplied.

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The Effects of Housing Prices and Monetary Policy in a Currency Union*

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The recent boom-and-bust cycle in housing prices has refreshed the debate on the drivers of housing cycles as well as the appropriate policy response. We analyze the case of Spain, where housing prices have soared since it joined the EMU. We present evidence based on a VAR model, and we calibrate a New Keynesian model of a currency area with durable goods to explain it. We find that labor market rigidities provide stronger amplification effects to all types of shocks than financial frictions do. Finally, we show that when the central bank reacts to house prices, the non-durable sector suffers an important contraction. As a result, the boom-and-bust cycle would not have been avoided if Spain had remained outside the EMU during the 1996–2007 period.

JEL Codes: E44, E52, F41.

1. Introduction

The recent boom-and-bust cycle in housing prices in many advanced economies has refreshed the debate on the drivers of housing cycles and the role of the housing sector in amplifying economic volatility, as well as the appropriate response of the monetary authorities. The case of Spain is of special interest since its recent economic expansion has been characterized by sustained growth of residential

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investment, private consumption, credit, and housing prices for more than a decade. Moreover, during this period nominal and real interest rates fell to exceptionally low levels during the convergence period in order to enter the european Economic and Monetary Union (EMU). As a result, a large current account deficit emerged, reaching almost 10 percent of GDP at the peak of the cycle in 2007.

In addition to growing external imbalances, a special source of concern for the Spanish economy was the loss of monetary policy autonomy after entering the EMU. In countries with their own national currency and monetary policy—such as the United States, the United Kingdom, Australia, and New Zealand—the central bank can increase interest rates to slow down the growth rate of housing prices (although in practice they were not successful in doing so in the most recent cycle), and also respond to a housing price collapse.[1] However, Spain belongs to the EMU, and the European Central Bank (ECB) sets rates according to the inflation rate of the Harmonized Index of Consumer Prices (HICP) of the euro area as a whole. This means that monetary policy cannot be the first line of defense in response to negative sector- and country-specific shocks.

The recent evolution of the Spanish economy since 1996, including the housing market boom-bust cycle, is shown in figures 1 through 4. Spain suffered from two developments going to the EMU: a loss of monetary autonomy and a large decline in interest rates. The period of convergence to and adoption of the euro (1996–2007) was also characterized by increased residential investment and house price growth rates. The demand for housing was further increased by the high levels of immigration and the baby boom generation (which peaked in the early 1970s in Spain) reaching adulthood, fueling residential investment and even further increasing house prices. This increase in housing prices raised wealth and borrowing capacity of house owners who, in principle, could use these mechanisms to finance other consumption.[2] The growing current account deficit is

[1]Mishkin (2007) suggested that in response to a 20 percent housing price drop in the United States, the Federal Reserve should cut interest rates between 75 and 175 basis points, depending on the assumptions about the transmission mechanism.

[2]However, we should note that estimates of the marginal propensity to consume out of housing wealth in Spain are lower than in other countries. Bover (2005) obtains estimates of about 0.01–0.02.

Figure 1. Nominal House Prices and Interest Rates

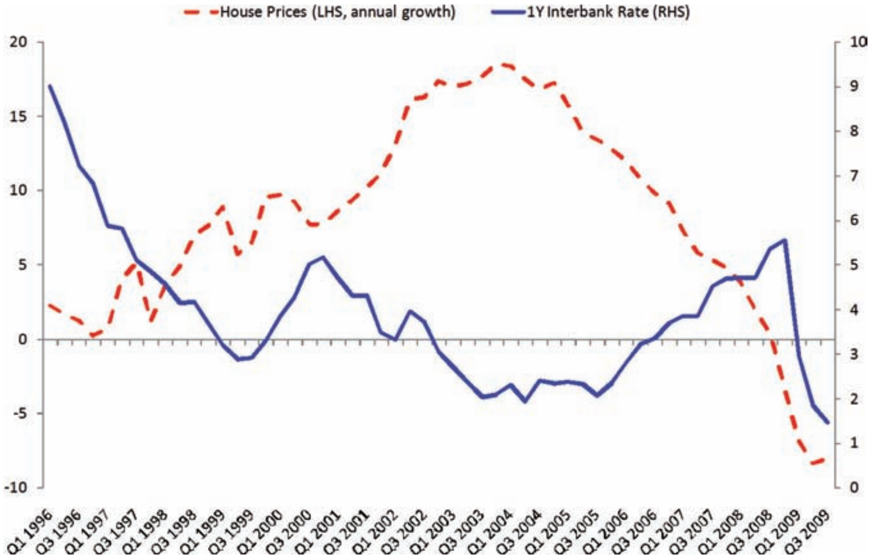


Figure 2. Residential Investment and Interest Rates

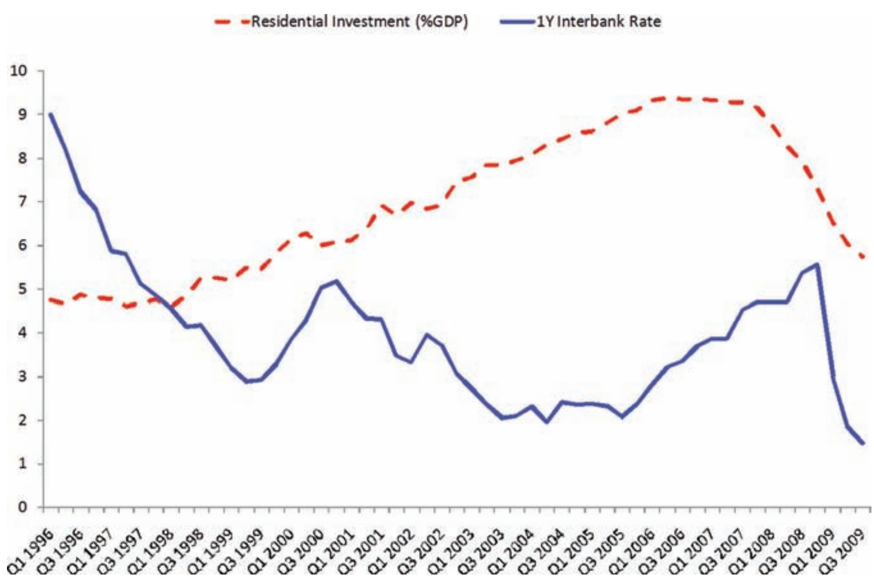
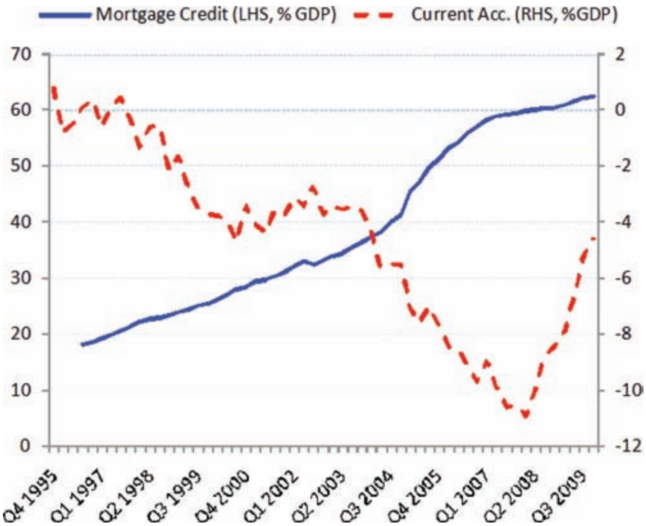
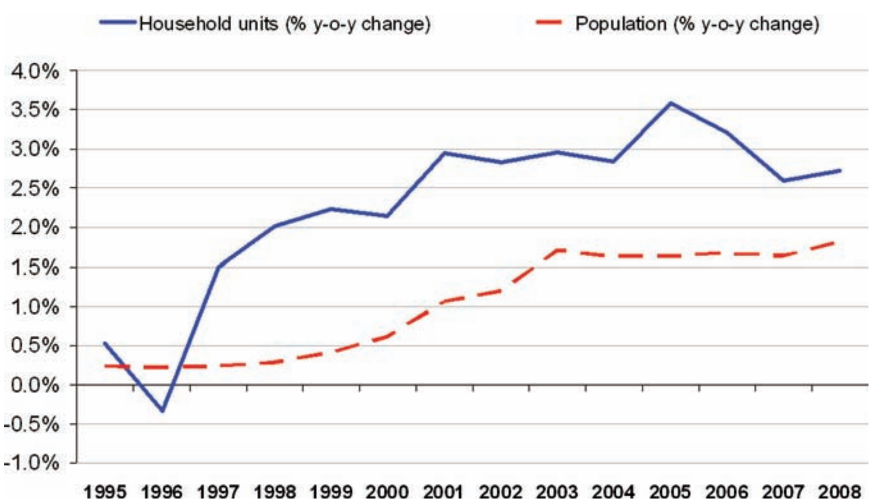


Figure 3. Mortgage Credit and the Current Account



the other indicator of the magnitude of the consumption and borrowing boom, and the large savings-investment imbalance was financed from abroad. Since late 2007, the boom cycle has turned into a bust.

Figure 4. Demographic Patterns



Hence, in this paper we study the response of a small economy in a currency union (such as the Spanish one) to fluctuations in housing prices and residential investment. First, we present VAR evidence that shows the response of private consumption, residential investment, aggregate GDP, and real house prices to an interest rate shock and to a housing demand shock. We show that a decrease in interest rates and a positive housing demand shock lead to a rise in both final consumption and residential investment, a finding labeled as "co-movement" in the literature when studying U.S. data.

We rationalize our findings by building a two-country, two-sector model of a currency union in the spirit of Benigno (2004) and Rabanal (2009). The model includes durable and non-durable goods. Holding durables (i.e., housing) not only provides utility to the consumer but is also a vehicle for savings. In addition, the international dimension of the model implies that the savings and investment balance need not hold period per period at the country level. This will allow us to explain how increased credit demand in one country of a currency union can be met through funds coming from elsewhere in the union. We calibrate the model and examine the reaction of domestic variables and the nominal interest rate to a monetary policy shock and a demand/preference shock in the durable sector. Overall, the demand shock and the interest rate shock produce effects on the main aggregates of the economy similar to the ones observed in the VAR.

Then, we conduct a robustness exercise to understand how important are labor market and credit market rigidities in understanding the transmission of housing demand and monetary shocks in the economy. As opposed to the existing literature that stresses the role of financial frictions and borrowing constraints to explain co-movement, we find that the effect of labor market rigidities has important implications for the persistent response of variables to shocks and to explain the co-movement between consumption and residential investment. Financial frictions amplify the monetary and preference shocks, but their quantitative effects are rather small when compared with a model with homogeneous agents and no credit constraints (but with labor market frictions). This does not mean credit constraints are not important. But they need to be modeled in a different way than has been included in the literature. One avenue to study would be to allow agents to borrow against their labor income, in addition to housing collateral.

In the last section of the paper we study the policy options for a small open economy, such as the Spanish one, that faces large sector-specific shocks. In addition to our benchmark currency union model, we consider two additional cases. In the first one, we assume that Spain follows a Taylor rule that is similar to the one followed by the rest of the EMU. In the second case, we examine what would have happened if the Spanish authorities, outside the euro, had tried to "lean against the wind" and included house price inflation in their reaction function. We find that if Spain had followed an inflation-targeting regime with a pure floating exchange rate, the monetary policy reaction to a domestic demand shock would not have been very different than that of belonging to a currency union. If we allow the central bank to react to house prices, the initial boom in housing inflation and residential investment can be reduced. However, to achieve stability in the housing market using the nominal interest rate as a policy tool leads to an important and persistent contraction in the non-durable sector. Hence, even if the Spanish authorities had kept monetary policy management, it is not clear that they would have chosen to "lean against the wind." It is important to note that this paper studies the 1996–2007 period, and the exercise only focuses on the possible costs of not being able to address demand-specific shocks in one sector or country using monetary policy. We show that these costs are small. Our model does not evaluate other important costs of not belonging to the EMU, such as those associated with exchange rate volatility (e.g., higher domestic interest rates and lower international trade), which could affect growth.

The rest of the paper is organized as follows. In section 2, we present some VAR-based evidence. In section 3, we present the model, and in section 4 we discuss at length the quantitative implications of the model. The robustness checks are presented in section 5, and in section 6 we analyze the effects of belonging to the EMU. We leave section 7 for concluding remarks.

2. The VAR Response to Housing Demand and Interest Rate Shocks

In this section, we present evidence on the response of main macroeconomic variables to housing demand and interest rate shocks with the help of a vector autoregressive (VAR) model. Several papers in the literature have studied the response of durable and non-durable consumption to a monetary policy shock using a VAR and the recursive identification scheme of Christiano, Eichenbaum, and Evans (1999, 2005). This approach consists of identifying the effect of the monetary policy shock by using the Cholesky decomposition of the variance-covariance matrix of the reduced-form residuals of the VAR. Papers following this approach include Erceg and Levin (2006) and Monacelli (2009).

In addition, we seek to identify a *housing demand* shock from the VAR. We do so by assuming that the housing demand shock affects the real price of housing within a period, but it does not affect its quantity: in the short run the supply of housing is fixed, and demand shocks must be absorbed via price movements. In practice, this shock leads to an increase of residential investment and prices, thereby confirming our labeling. In the last part of the section, we discuss several robustness results that include introducing euro-area variables into the system, extending the sample period, and using sign restrictions to identify the housing demand shock.

We estimate the following VAR using k variables:

$$Y_t = C + \sum_{j=1}^{L} A_j Y_{t-j} + B u_t,$$

where Y_t is a $k \times 1$ vector of observable variables, C is a $k \times 1$ vector of constants, A_j are $k \times k$ matrices that collect the effect of endogenous variables at lag j on current variables, L is the lag length in the VAR, B is a $k \times k$ lower triangular matrix with diagonal terms equal to unity, and u_t is a $k \times 1$ vector of zero-mean, serially uncorrelated shocks with a diagonal variance-covariance matrix.

The vector of endogenous variables is divided as follows: $Y_t = [Y_{1t} \quad R_t \quad Y_{2t}]'$, where Y_{1t} is a group of macroeconomic variables predetermined when monetary policy decisions are taken, R_t is a relevant interest rate, and Y_{2t} contains the variables affected contemporaneously by monetary policy decisions. As is customary in the literature, to identify the interest rate shock we place the nominal interest rate after the macroeconomic variables. On the other hand, we assume that house prices can respond to changes in monetary policy within a period: as an asset price, housing prices are likely to respond contemporaneously to changes in the nominal interest rate, so we include them in Y_{2t}. Hence, we identify the housing demand shock as the shock that affects housing prices within a period, after taking into account the effect that changes in the interest rate have on housing prices.[3]

2.1 Data

The vector of observable variables is divided the following way. In Y_{1t} we include (i) real household consumption of final goods in Spain, (ii) real residential investment in Spain, and (iii) real GDP in Spain. We use as a relevant interest rate (R_t) the reference interbank rate. Finally, we include in Y_{2t} real house prices in Spain. All variables are introduced in the VAR in levels after taking natural logarithms, except for the nominal interest rate that we introduce directly in levels.

Private consumption, residential investment, and GDP come from Spanish national accounts data and are deflated by the Spanish GDP deflator. Nominal housing prices come from the OECD and are deflated by the HICP in Spain. In studies involving U.S. data, the federal funds rate is typically the variable used as an indicator of the stance of monetary policy, following the study of Bernanke and Blinder (1992). Spain relinquished its monetary policy autonomy when it joined the EMU January 1, 1999, and hence a domestic reference rate is no longer available. We choose the three-month interbank rate as the reference interest rate. From 1999 we use the three-month Euribor rate, and before the EMU period we use the three-month MIBOR rate (the Madrid Interbank rate). Note that because of this reason, we call our shock an interest rate shock rather than a monetary policy shock in the VAR.

The relevant interbank interest rate for mortgages in Spain is the twelve-month rate. In practice, using the three-month or the twelve-month rate delivers the same results, since the reference rate set by the ECB, the three-month interbank rate, and the twelve-month interbank rate move very closely together. We estimate the VAR from 1997:01 to 2008:04 at a quarterly frequency, with two lags.

[3]We have also estimated a VAR with the ordering $Y_t = [Y_{1t} \quad Y_{2t} \quad R_t]'$ and the results are very similar to the ones we present.

While the euro was launched in 1999, monetary policy in Spain followed its European counterparts closely in 1997–98, and this allows us to include eight more observations in the system.

2.2 Results

In figures 5 and 6 we present the impulse responses of the five variables to an increase in interest rates and a housing demand shock. We present the mean and 85 percent confidence bands.[4] In order to better interpret the VAR evidence, we present impulse responses to a 25-basis-point interest rate shock and to a housing demand shock that increases residential investment by 10 percent in the second period (by construction, the housing demand shock only affects prices in the initial period). An interest rate shock of 25 basis points is followed by further increases in the interest rate, which leads to a decline of real consumption of 0.6 percent after twelve quarters and a decline of 2 percent of residential investment after seven quarters. This higher responsiveness of durable consumption and residential investment has been found in other papers such as Erceg and Levin (2006) and Monacelli (2009). The increase in interest rates also leads to a decline of real house prices of 2 percent after seven quarters.

On the other hand, the housing demand shock leads to an increase of real house prices of 8 percent and an increase of residential investment of 10 percent after one period. There are significant spillovers to the rest of the economy, and both private consumption and real GDP increase by more than 1 percent after ten quarters.

These are the features that our model will reproduce, in particular the co-movement in the response of both private consumption and residential investment to shocks.

2.3 Variance Decomposition

The results of the variance decomposition are presented in table 1. Since we attempt to identify the effects of interest rate and housing

[4]Given the short sample, it is difficult to obtain significance at the conventional 95 percent interval.

Figure 5. Impulse Response from VAR, Monetary Policy Shock

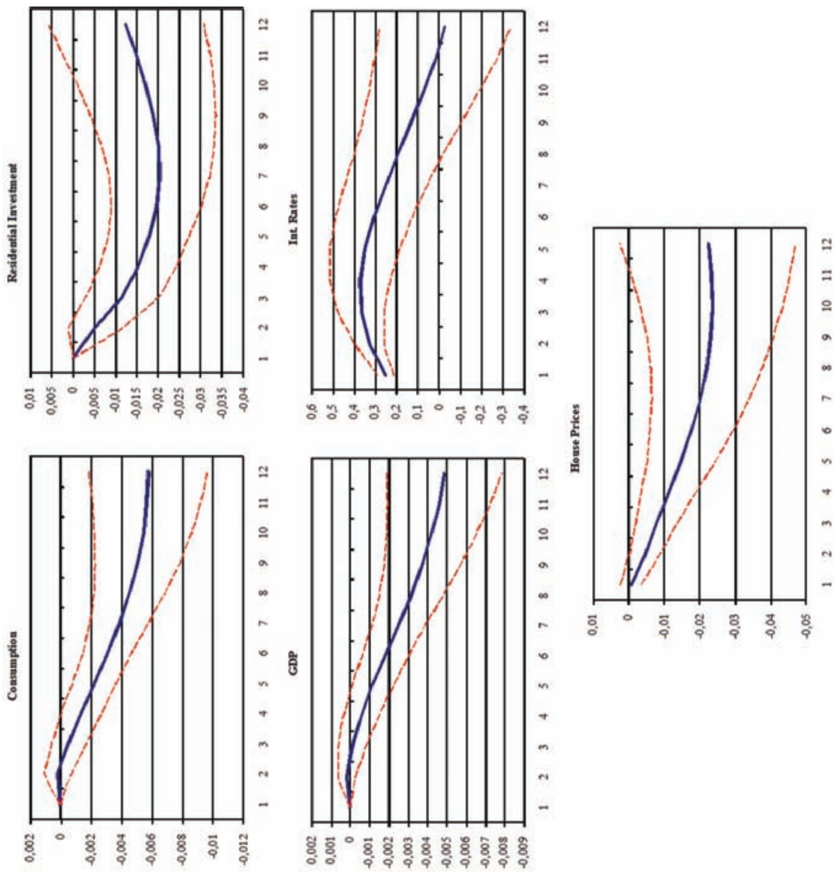


Figure 6. Impulse Response from VAR, Housing Demand Shock

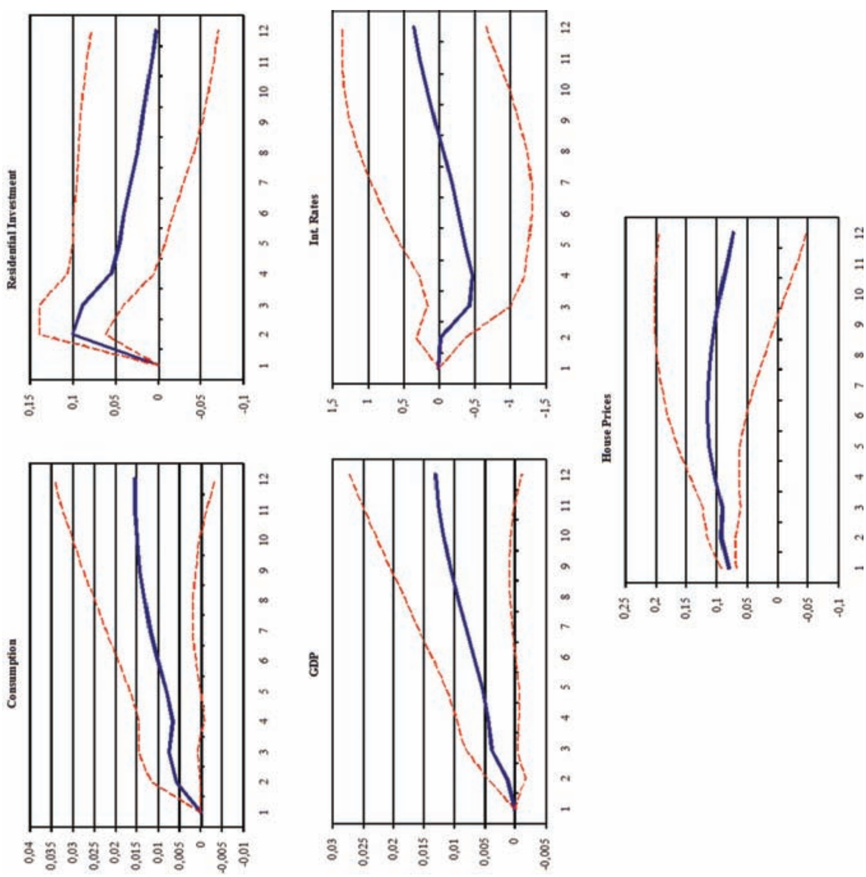


Table 1. Variance Decomposition VAR

	Consumption			Investment			Real GDP			Interest Rate			House Prices		
Horizon	**MP**	**HD**	**Other**	**MP**	**HD**	**Other**	**MP**	**HD**	**Other**	**MP**	**HD**	**Other**	**MP**	**HD**	**Other**
1	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0	96.4	0.0	3.6	0.1	84.9	15.1
2	0.2	4.4	95.4	1.2	18.1	80.6	0.0	0.2	99.8	79.6	0.8	19.5	2.2	71.8	26.0
3	0.2	7.5	92.3	2.9	25.8	71.3	0.2	2.0	97.9	66.7	4.7	28.6	6.0	54.6	39.4
4	1.3	10.4	88.3	5.0	28.3	66.6	1.1	4.1	94.9	55.5	8.0	36.5	9.6	42.3	48.2
5	4.1	13.9	82.0	7.3	29.3	63.3	3.1	6.7	90.2	46.8	10.1	43.0	12.0	35.0	53.0
10	19.2	26.0	54.8	13.1	28.5	58.5	19.1	23.6	57.3	29.4	12.9	57.6	14.0	24.1	61.9
15	17.9	25.4	56.6	12.8	26.5	60.7	19.3	25.9	54.8	27.7	12.9	59.4	12.9	22.6	64.6
25	15.0	24.0	61.0	12.1	25.5	62.4	15.6	24.3	60.1	27.4	13.1	59.5	12.3	22.4	65.3

demand shocks, we present the fraction of the variance decomposition for these two shocks only and assign the remaining share to the aggregate of the other unspecified three shocks in the VAR system. Housing demand shocks explain a small fraction of the variance decomposition of private consumption and real GDP at short horizons, but at longer horizons (starting at ten quarters) their contribution rises to about 25 percent. Housing demand shocks explain a similar fraction of the variance decomposition of investment at both short and long horizons. Interest rate shocks explain an important part of the variance decomposition of real variables at long horizons, between 10 and 20 percent depending on the variable. Finally, both interest rates and house price variance decompositions are driven by their own shock at short horizons but by the "other shocks" in the model (60 percent of the share) at longer horizons.

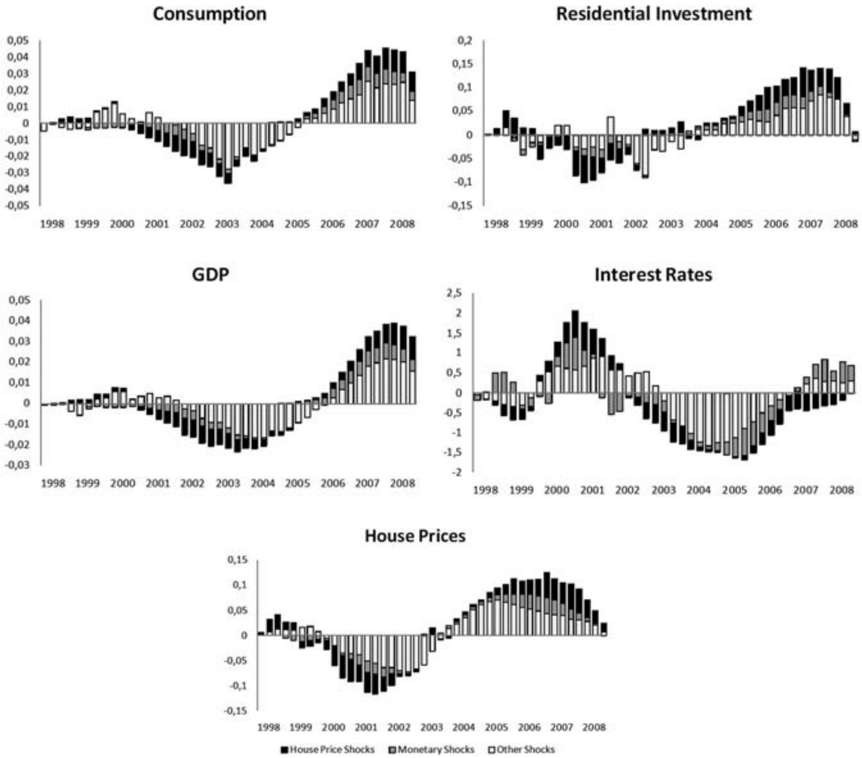
2.4 Historical Decomposition

Figure 7 presents the contribution of each shock in explaining the deviation of the actual data from the balanced growth path of the system in the absence of shocks. It becomes evident that most fluctuations are driven by the shocks that we do not attempt to identify in the VAR, but both monetary policy and housing demand shocks also played an important role. It is interesting to note that contractionary monetary policy shocks and negative housing demand shocks help explain the slowdown in 2002–03. At the same time, both shocks, and in particular housing demand shocks, had a very strong effect in the most recent boom since 2004, fueling house prices, residential investment, private consumption, and real GDP.

2.5 Robustness

We have conducted several robustness exercises with our VAR-based evidence, which are not presented here to save space but are available upon request. In the first extension, we include the Harmonized Index of Consumer Prices (HICP) inflation and real GDP growth in the euro area to control for the endogenous response of interest rates. In this case, we find that the qualitative results do not change. This suggests that, from the Spanish perspective, changes in interest rates can be seen as purely exogenous shocks. Second,

Figure 7. Historical Decomposition from the VAR



we have also experimented by using the sample period 1980–2008. All the results are very similar to the ones presented here, except in the response of real house prices to a monetary policy shock, which is small and non-significant. Finally, we have used sign restrictions as in Uhlig (2005) and Cardarelli et al. (2009) to identify the effects of housing demand, housing supply, and monetary policy shocks, and found that the main message of figures 5 and 6 does not change.

3. The Model

The theoretical framework consists of a general equilibrium two-country, two-sector model in a single currency area. The countries are of size n and $1 - n$, and each of them produces two types of goods—durables and non-durables—under monopolistic competition and nominal rigidities. Only the non-durable goods are tradable. Producers of the final durable good sell their products to domestic households only in each country, which allows them to increase their housing stock. For this reason, we use the terms "durable goods production" and "residential investment" interchangeably throughout the paper.

Since our VAR analysis has only focused on the effects of monetary and demand shocks on the housing sector and the spillover effects to the macroeconomy, the model will only include these shocks, so we leave aside technology shocks in the current analysis. In what follows, we present the home country block of the model. The analogous foreign country variables will be denoted by an asterisk.

3.1 Households

Each household j in the home country maximizes the following utility function:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\gamma \log \left(C_t^j - \varepsilon C_{t-1} \right) + (1-\gamma) \xi_t^D \log \left(D_t^j \right) - \frac{\left(L_t^j \right)^{1+\eta}}{1+\eta} \right] \right\}, \tag{1}$$

where C_t^j denotes consumption of non-durable goods, D_t^j denotes consumption of durable goods, and L_t^j is the labor disutility index. ξ_t^D is a housing preference shock, which follows an AR(1) process in logs.

The utility function denotes external habit formation, as in Smets and Wouters (2003) and Iacoviello and Neri (2010). β is the discount factor and η is the inverse elasticity of labor supply. The parameter ε denotes the importance of the habit stock, which is last period's aggregate consumption (C_{t-1}). In addition, consumption of non-durables is an index composed of home and foreign consumption goods:

$$C_t^j = \left[\tau^{\frac{1}{\iota_C}} \left(C_{H,t}^j \right)^{\frac{\iota_C - 1}{\iota_C}} + (1-\tau)^{\frac{1}{\iota_C}} \left(C_{F,t}^j \right)^{\frac{\iota_C - 1}{\iota_C}} \right]^{\frac{\iota_C}{\iota_C - 1}}, \text{ where } \iota_C > 0, \tag{2}$$

where $C^j_{H,t}$ and $C^j_{F,t}$ are, respectively, consumption of the home non-durable goods and consumption of foreign non-durable goods by the home agent, and τ is the fraction of domestically produced non-durables at home. Finally, following Iacoviello and Neri (2010), we assume that there is imperfect substitutability of labor supply across sectors, such that the labor disutility index can be written as

$$L^j_t = \left[\alpha^{-\iota_L}\left(L^{C,j}_t\right)^{1+\iota_L} + (1-\alpha)^{-\iota_L}\left(L^{D,j}_t\right)^{1+\iota_L}\right]^{\frac{1}{1+\iota_L}}, \text{ where } \iota_L > 0, \quad (3)$$

where $L^{i,j}_t$ denotes hours worked by household j in each sector $i = C, D$, and α is the economic size of each sector. This imperfect substitutability implies that there is a costly labor reallocation across sectors following a shock. Note that when $\iota_L = 0$, the aggregator is linear in hours worked in each sector, so there are no costs of switching from working in one sector to the other.[5]

The budget constraint of the home agent, in nominal terms, is given by

$$P^C_t C^j_t + P^D_t I^{D,j}_t + P^A_t A^j_t + B^j_t \leq \tilde{R}_{t-1} B^j_{t-1} + \frac{W^C_t L^{C,j}_t}{X^C_t} + \frac{W^D_t L^{D,j}_t}{X^D_t} + (R^A_t + P^A_t)A^j_{t-1} + \Pi^j_t, \quad (4)$$

where P^C_t and P^D_t are the price indices of durable and non-durable goods, to be defined below; W^i_t is the nominal wage in each sector $i = C, D$; and B^j_t denotes non-contingent nominal assets that are traded among households across the monetary union, and that pay (or cost) a gross nominal interest rate $\tilde{R}_t > 1$. Following Iacoviello and Neri (2010), X^j_t denotes the markup (due to monopolistic competition in the labor market) between the wage paid by intermediate firms and the wage that households receive (the details of the nominal rigidities in the labor market are discussed below). Π^j_t denotes nominal profits, because firms are ultimately owned by households. A_t denotes the level of land owned by households, which is purchased at a price P^A_t and which is rented to durable intermediate goods producers at a rental rate of R^A_t.

[5]Labor market rigidities could be a proxy for other real rigidities, such as product market entry, that the model does not include.

$I_t^{D,j}$ denotes residential investment to increase the housing stock. We assume that the law of motion of the housing stock evolves as follows:

$$D_t^j = (1-\delta)D_{t-1}^j + \left[1 - S\left(\frac{I_t^{D,j}}{I_{t-1}^{D,j}}\right)\right] I_t^{D,j}, \tag{5}$$

where δ denotes the rate of depreciation of the housing stock and, following Christiano, Eichenbaum, and Evans (2005), we introduce an adjustment cost function, $S(.)$, which is convex (i.e., $S''() > 0$). Furthermore, in the steady state, $\bar{S} = \bar{S}' = 0$ and $\bar{S}'' > 0$. The aim of introducing this cost is to allow for the possibility that the model can generate hump-shaped responses of residential investment to shocks.

We assume that households in the home country have to pay a premium above the union-wide riskless nominal interest rate as the country's debt level as a percentage of GDP increases. This assumption is needed to obtain a well-defined steady state for the aggregate level of debt.[6] The relevant interest rate for the home country households and the union-wide interest are related as follows:

$$\tilde{R}_t = R_t - \exp\left[\kappa\left(\frac{B_t}{P_tY_t} - \frac{B}{PY}\right)\right] - 1, \tag{6}$$

where P_t is the aggregate price level, to be defined below, and Y_t is real GDP, also to be defined below. R_t is the riskless interest rate and κ is the risk premium elasticity. This risk premium depends on aggregate variables, such that each household takes this effect as given when choosing between consuming durables, non-durables, and saving. Note that the risk premium is declining in the net foreign asset position of the country as a percentage of GDP, $\frac{B_t}{P_tY_t}$.

We can separate the household's decision in a two-stage process. First, households choose the amount of labor to supply to each sector, and the consumption of durables and non-durables. Second, they allocate how much to spend on home- and foreign-produced goods, taking into account that

$$P_t^C C_t = P_{H,t}C_{H,t} + P_{F,t}C_{F,t},$$

[6]See Schmitt-Grohé and Uribe (2003).

where $P_{H,t}$ denotes the price of home non-durable consumption goods and $P_{F,t}$ the price of foreign non-durable consumption goods. The variables corresponding to the foreign country are denoted with an asterisk, but the prices of foreign non-durable consumption goods do not carry it because they are also set in euros, and there is no price discrimination across countries.

The first-order conditions to the household problem are given by[7]

$$U_{C_t} = \lambda_t P_t^C \tag{7}$$

$$U_{D_t} = \mu_t - \beta(1-\delta)E_t\mu_{t+1} \tag{8}$$

$$\lambda_t P_t^D = \mu_t \left\{1 - S\left(\frac{I_t^D}{I_{t-1}^D}\right) - S'\left(\frac{I_t^D}{I_{t-1}^D}\right)\frac{I_t^D}{I_{t-1}^D}\right\} + \beta E_t\mu_{t+1}\left[S'\left(\frac{I_{t+1}^D}{I_t^D}\right)\left(\frac{I_{t+1}^D}{I_t^D}\right)^2\right]. \tag{9}$$

Absent adjustment costs to residential investment, these three equations can be reduced to the following condition:

$$\frac{P_t^D}{P_t^C} = \frac{1-\gamma}{\gamma}\frac{\xi_t^D(C_t - \varepsilon C_{t-1})}{D_t} + \beta(1-\delta)E_t\left[\left(\frac{C_t - \varepsilon C_{t-1}}{C_{t+1} - \varepsilon C_t}\right)\frac{P_{t+1}^D}{P_{t+1}^C}\right].$$

Note that if the durable good was in fact non-durable (i.e., $\delta = 1$), this condition simply states that the marginal utilities of consumption should equal relative prices. Since the durable good has a residual value the following period, this induces the extra term of holding an additional unit of the durable good.

A standard Euler equation for the consumption of non-durable goods is

$$1 = \beta\tilde{R}_t E_t\left[\frac{P_t^C}{P_{t+1}^C}\left(\frac{C_t - \varepsilon C_{t-1}}{C_{t+1} - \varepsilon C_t}\right)\right]. \tag{10}$$

[7]Since all households behave the same way, we drop the j subscripts in what follows.

A similar Euler equation for land is as follows:

$$\tilde{R}_t = E_t \left(\frac{R^A_{t+1} + P^A_{t+1}}{P^A_t} \right) \tag{11}$$

such that households are indifferent between investing in land and riskless bonds. The allocation of non-durable consumption expenditures between home- and foreign-produced goods is

$$C_{H,t} = \tau \left(\frac{P_{H,t}}{P^C_t} \right)^{-\iota_C} C_t \tag{12}$$

$$C_{F,t} = (1-\tau) \left(\frac{P_{F,t}}{P^C_t} \right)^{-\iota_C} C_t. \tag{13}$$

The price index for non-durables is (the CPI):

$$\left(P^C_t\right)^{1-\iota_C} = [\tau (P_{H,t})^{1-\iota_C} + (1-\tau)(P_{F,t})^{1-\iota_C}]. \tag{14}$$

The utility maximization problem of foreign country households is quite similar. We assume that the functional forms for preferences are the same across countries, but allow for different parameter values. That is, γ^* is the weight of non-durables in the utility function, and τ^* is the fraction of domestically produced non-durables.

3.2 Wage Setting

Nominal wage stickiness is introduced as in Smets and Wouters (2003) and Iacoviello and Neri (2010), so we omit most functional forms here and refer the interested reader to those papers. Households supply homogeneous labor services to unions. These unions differentiate these labor services and set wages subject to a Calvo (1983)-type restriction, where the probabilities in each sector of not being able to readjust wages in a given period are $\theta_{C,W}$ and $\theta_{D,W}$. They offer these labor services to wholesale labor packers, who reassemble these services into homogeneous labor composites, which are in turn hired by intermediate firms from these packers.

Under Calvo wage setting and with partial indexation to past non-durable (CPI) inflation (with coefficients $\varphi_{C,W}$ and $\varphi_{D,W}$), the wage-setting equations can be log-linearized into the following wage Phillips curves, where lowercase variables denote percent deviations from steady-state values:

$$\omega_t^C - \omega_{t-1}^C + \Delta p_t^C - \varphi_{C,W}\Delta p_{t-1}^C$$
$$= \beta E_t\big(\omega_{t+1}^C - \omega_t^C + \Delta p_{t+1}^C - \varphi_{C,W}\Delta p_t^C\big)$$
$$+ \kappa^{C,W}\left[\frac{c_t - \varepsilon c_{t-1}}{1-\varepsilon} + [(\varphi-\iota)\alpha + \iota]l_t^C + (\varphi-\iota)(1-\alpha)l_t^D - \omega_t^C\right], \tag{15}$$

where $\kappa^{C,W} = \frac{(1-\theta_{C,W})(1-\beta\theta_{C,W})}{\theta_{C,W}}$, and

$$\omega_t^D - \omega_{t-1}^D + \Delta p_t^C - \varphi_{D,W}\Delta p_{t-1}^C$$
$$= \beta E_t\big(\omega_{t+1}^D - \omega_t^D + \Delta p_{t+1}^C - \varphi_{D,W}\Delta p_t^C\big)$$
$$+ \kappa^{D,W}\left[\frac{c_t - \varepsilon c_{t-1}}{1-\varepsilon} + [(\varphi-\iota)(1-\alpha) + \iota]l_t^D + (\varphi-\iota)\alpha l_t^C - \omega_t^D\right], \tag{16}$$

where $\kappa^{D,W} = \frac{(1-\theta_{D,W})(1-\beta\theta_{D,W})}{\theta_{D,W}}$.

3.3 Producers

There is a continuum of intermediate goods producers, indexed by $h \in [0, n]$ in the home country and by $f \in [n, 1]$ in the foreign country, that are imperfect substitutes of each other and that supply final goods producers in each sector. There is a continuum of final goods producers in the two sectors that operate under perfect competition and flexible prices. Producers of the final durable good sell their products to domestic households only in each country. Producers of the final non-durable good sell their products to domestic and foreign households. Hence, it is important to distinguish the price level of domestic non-durable consumption goods, $P_{H,t}$, which does not coincide with the price level of non-durables or CPI (P_t^C) because of the presence of imported non-durable goods, whose price is $P_{F,t}$.

3.3.1 Final Goods Producers

In the durable sector, final goods producers purchase intermediate goods producers and aggregate them according to the following production function:

$$Y_t^D \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_D}} \int_0^n Y_t^D(h)^{\frac{\sigma_D - 1}{\sigma_D}} dh \right]^{\frac{\sigma_D}{\sigma_D - 1}} . \qquad (17)$$

Profit maximization delivers the following demand for individual, intermediate non-durable goods:

$$Y_t^D(h) = \left(\frac{P_t^D(h)}{P_t^D} \right)^{-\sigma_D} Y_t^D, \qquad (18)$$

where the price level is given by imposing the zero-profit condition,

$$P_t^D \equiv \left\{ \frac{1}{n} \int_0^n \left[P_t^D(h) \right]^{1-\sigma_D} dh \right\}^{\frac{1}{1-\sigma_D}} .$$

In the non-durable goods sector, expressions are similar but with an appropriate change of notation since the price level of domestic non-durables and of a basket of durables is not the same. The aggregate production function is

$$Y_t^C \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\sigma_C}} \int_0^n Y_t^C(h)^{\frac{\sigma_C - 1}{\sigma_C}} dh \right]^{\frac{\sigma_C}{\sigma_C - 1}} ; \qquad (19)$$

individual intermediate non-durable goods demand is

$$Y_t^C(h) = \left(\frac{P_t^H(h)}{P_t^H} \right)^{-\sigma_C} Y_t^C, \qquad (20)$$

where the price level is

$$P_t^H \equiv \left\{ \frac{1}{n} \int_0^n \left[P_t^H(h) \right]^{1-\sigma_C} dh \right\}^{\frac{1}{1-\sigma_C}} .$$

3.3.2 Intermediate Goods Producers

There is a continuum of intermediate goods producers, indexed by $h \in [0, n]$ in the home country and by $f \in [n, 1]$ in the foreign country, that are imperfect substitutes of each other and that supply final goods producers in each sector. Intermediate goods producers face a Calvo-type restriction when setting their price. In each period, a fraction $1 - \theta_i$ in each sector $(i = C, D)$ receives a signal to reset prices optimally. In addition, a fraction ϕ_i $(i = C, D)$ index their price to last period's sectorial inflation rate whenever unable to reoptimize.

Intermediate non-durable goods in both countries are produced with labor:

$$\begin{aligned} Y_t^C(h) &= L_t^C(h), \text{ for all } h \in [0, n]. \\ Y_t^C(f) &= L_t^C(f), \text{ for all } f \in [n, 1]. \end{aligned} \tag{21}$$

Intermediate goods in the durable sector are produced combining land and labor with the following Cobb-Douglas production function:

$$\begin{aligned} Y_t^D(h) &= (A_{t-1})^{1-\alpha_D} \left[L_t^D(h)\right]^{\alpha_D}, \text{ for all } h \in [0, n]. \\ Y_t^D(f) &= (A_{t-1})^{1-\alpha_D} \left[L_t^D(f)\right]^{\alpha_D}, \text{ for all } f \in [n, 1], \end{aligned} \tag{22}$$

where α_D denotes the labor share in the housing sector. In the remaining part of this subsection, we work out the conditions for the home country firms' pricing decisions. In the non-durable sector, cost minimization implies that the real marginal cost of production equals the real wage:

$$MC_t^C = \frac{W_t^C}{P_t^C}. \tag{23}$$

In the durable sector, after imposing that the supply of land is fixed $(A_t = \bar{A})$, the marginal cost is given by

$$MC_t^D = \frac{1}{\alpha^D} \frac{W_t^D}{P_t^C} \left(L_t^D\right)^{1-\alpha^D} (\bar{A})^{-(1-\alpha^D)}, \tag{24}$$

where we have substituted for the optimal expression of the rental rate of land:[8]

$$R_t^A = \left(\frac{1-\alpha^D}{\alpha^D}\right)\frac{W_t^D L_t^D}{\bar{A}}.$$

Firms in the durable sector face the following maximization problem:

$$Max_{P_t^D(h)} E_t \sum_{k=0}^{\infty} \theta_D^k \Lambda_{t,t+k} \left\{ \left[\frac{P_t^D(h)\left(\frac{P_{t+k-1}^D}{P_{t-1}^D}\right)^{\phi_D}}{P_{t+k}^D} - MC_{t+k}^D \right] Y_{t+k}^D(h) \right\}$$

subject to future demand

$$Y_{t+k}^D(h) = \left[\frac{P_t^D(h)}{P_{t+k}^D} \left(\frac{P_{t+k-1}^D}{P_{t-1}^D} \right)^{\phi_D} \right]^{-\sigma_D} Y_{t+k}^D,$$

where $\Lambda_{t,t+k} = \beta^k \frac{\lambda_{t+k}}{\lambda_t}$ is the stochastic discount factor, and λ_t is the marginal utility of non-durable consumption.

The optimal choice is given by

$$\frac{\hat{P}_t^D}{P_t^D} = \frac{\sigma_D}{(\sigma_D - 1)} E_t \times \left\{ \frac{\sum_{k=0}^{\infty} \beta^k \theta_D^k \lambda_{t+k} \left(\prod_{s=1}^{k} \frac{\left(\Pi_{t+s-1}^D\right)^{\phi_D}}{\Pi_{t+s}^D} \right)^{-\sigma_D} MC_{t+k}^D Y_{t+k}^D}{\sum_{k=0}^{\infty} \beta^k \theta_D^k \lambda_{t+k} \left(\prod_{s=1}^{k} \frac{\left(\Pi_{t+s-1}^D\right)^{\phi_D}}{\Pi_{t+s}^D} \right)^{1-\sigma_D} Y_{t+k}^D} \right\}. \quad (25)$$

Given the assumptions about Calvo pricing, the evolution of the price level is

$$P_t^D = \left\{ \theta_D \left[P_{t-1}^D \left(\Pi_{t-1}^D\right)^{\phi_D} \right]^{1-\sigma_D} + (1-\theta_D)\left(\hat{P}_t^D\right)^{1-\sigma_D} \right\}^{\frac{1}{1-\sigma_D}}. \quad (26)$$

[8]We choose the level of $\bar{A}$, such that the level of real wages is the same across sectors in the steady state.

Firms in the non-durable sector face a similar maximization problem, and hence the optimal price and the evolution of the price level have similar expressions, with the appropriate change of notation.

3.4 Closing the Model

3.4.1 Market Clearing Conditions

In each intermediate good, supply equals demand. We write the market clearing conditions in terms of aggregate quantities. Hence, we multiply per capita quantities by population size of each country. Total production in the non-durable sector is equal to total domestic consumption and exports,

$$Y_t^C = nC_{H,t} + (1-n)C_{H,t}^*, \tag{27}$$

while residential investment is used to increase the domestic housing stock,

$$Y_t^D = n[D_t - (1-\delta)D_{t-1}]. \tag{28}$$

Total hours worked equals labor supply in each sector:

$$\int_0^n L_t^C(h)dh = \int_0^n L_t^{C,j}dj \tag{29}$$

$$\int_0^n L_t^D(h)dh = \int_0^n L_t^{D,j}dj. \tag{30}$$

Market clearing in the international bonds market is

$$nB_t + (1-n)B_t^* = 0. \tag{31}$$

Finally, the evolution of aggregate net foreign assets is

$$nB_t = n\tilde{R}_{t-1}B_{t-1} + (1-n)P_{H,t}C_{H,t}^* - nP_{F,t}C_{F,t}. \tag{32}$$

3.4.2 Monetary Policy Rule

In order to close the model, we need to specify a rule for monetary policy, which is conducted by the ECB with an interest rate rule that targets CPI inflation and also exhibits interest rate inertia:

$$R_t = \left[\bar{R} \left(\frac{P_t^{EMU}/P_{t-1}^{EMU}}{\bar{\Pi}^{EMU}} \right)^{\gamma_\Pi} \right]^{1-\gamma_R} R_{t-1}^{\gamma_R} \exp\left(\varepsilon_t^m\right), \tag{33}$$

where the euro-area CPI is given by a geometric average of the home and foreign country CPIs, using the country size as a weight:

$$P_t^{EMU} = \left(P_t^C\right)^n \left(P_t^{C^*}\right)^{1-n}.$$

4. Calibration

In the steady state, we assume zero inflation, a trade balance of zero, and that the net international position of both economies is zero. Therefore, we only need to solve for the per capita values of the home country, which are the same as those in the foreign country. We also assume that the degree of monopolistic competition in both types of goods is the same ($\sigma_C = \sigma_D = \sigma$), and hence the ratio of prices is one. Now, we solve for the levels of consumption of durables, non-durables, hours, and the economic size of each sector. The optimal steady-state ratio of durable to non-durable consumption is

$$\frac{C}{D} = \frac{\gamma[1-\beta(1-\delta)]}{1-\gamma} = \Omega. \tag{34}$$

The fraction of spending allocated to non-durable consumption over total spending (α) is equal to

$$\frac{C}{C+\delta D} = \alpha.$$

Note that γ and α cannot be calibrated independently. Given values for α, δ, and β, we can solve for the value of γ in the utility function.

To ensure that the level of real wages in both sectors is the same (despite different labor shares), we need to calibrate $\bar{A} = (\frac{1}{\alpha^D})^{\frac{1}{1-\alpha_D}L^D}$. As a result, from the labor supply conditions by households,

$$(1-\alpha)L^C = \alpha L^D, \tag{35}$$

which means that agents spend a fraction α of time working in the non-durable sector and a fraction $1-\alpha$ in the durable sector.

Table 2. Calibrated Parameters of the Model

n	Size of Spain inside the EMU	0.1
α	Share of the non-durable sector in the GDP	0.9
$1-\tau$	Fraction of EMU imports consumed in Spain	0.15
$1-\tau^*$	Fraction of Spain imports goods consumed in the EMU	0.015
κ	Debt elasticity of the domestic interest rate	0.02
σ_C, σ_D	Elasticity of substitution between intermediate goods	10
β	Discount factor	0.99
δ	Depreciation rate of housing stock	0.025
ε	Habit formation	0.4
η	Labor supply elasticity	0.9
ι_C	Elasticity of substitution between goods	4.4
ι_L	Costly labor reallocation	1.3
γ	Share of non-durable consumption in the Utility Function	0.82
ψ	Investment adjustment costs	0.3
θ_C	Calvo lottery for the non-durable sector, prices	0.87
θ_D	Calvo lottery for the durable sector, prices	0.34
$\theta_{C,W}$	Calvo lottery for the non-durable sector, wages	0.75
$\theta_{D,W}$	Calvo lottery for the durable sector, wages	0.75
ϕ_C	Price indexation, non-durables	0.5
ϕ_D	Price indexation, durables	0.7
$\phi_{C,W}$	Wage indexation, non-durables	1
$\phi_{D,W}$	Wage indexation, durables	1
γ^π	Inflation parameter of the Taylor rule	1.25
γ^R	Interest rate smoothing parameter of the Taylor rule	0.77

Table 2 summarizes the values of the exogenous and endogenous parameters of the model. We set as the home country Spain, and the foreign country the rest of the EMU. Hence, we set the size of the home economy to $n = 0.1$. We set the size of the construction sector at $1 - \alpha = 0.1$, both in Spain and in the EMU, which is roughly the average size for the value added of the construction sector in the last decade. We calibrate the bilateral trade parameter (τ) based on total imports from the EMU to Spain over total spending, and calibrate its analogous parameter in the EMU (τ^*) in a similar way.

For the parameter capturing the debt elasticity to the domestic interest rate, as well as the technology, preference, and nominal rigidities parameters, we use the estimated values in a companion paper of ours.[9] In that paper, we imposed the same parameter values across countries (except the bilateral imports ratio), so we follow this strategy here. Therefore, the value for κ is fixed to 0.02, which captures the idea that interest rates spreads between Spain and the EMU have been negligible during this period. In Aspachs-Bracons and Rabanal (2010), the posterior mean estimate for the labor market rigidities, ι_L, is 1.2, a value that is very similar to the one estimated by Iacoviello and Neri (2010) using U.S. data. We also calibrate the degree of habit formation ε, the elasticity of labor supply η, the elasticity of substitution between home and foreign goods ι_C, and the investment adjustment cost parameter ψ from our companion paper.

Having calibrated the real side of the economy, we now proceed to discuss the calibration of the degree of nominal rigidity in each sector and country. In the literature, there is a long-standing debate on the degree of nominal rigidities between housing and the other sectors of the economy, and how this might affect the transmission mechanism of monetary policy. For instance, Carlstrom and Fuerst (2006) use the evidence on frequency of price adjustments in the durable and non-durable sectors of Bils and Klenow (2004) to argue that prices in the housing sector are more flexible than in the consumption goods sector. Using this calibration is problematic because, in the model, a monetary contraction leads to an expansion of residential investment that is at odds with the data. This result arises because the differing degree of nominal rigidity across sectors causes a strong movement of relative prices.

We also use the values estimated in Aspachs-Bracons and Rabanal (2010) to calibrate the nominal rigidities. Hence, we set prices to be more sticky in the non-durable sector, $\theta_C = 0.87$, than in durable goods, $\theta_D = 0.34$. Nominal rigidities parameters are assumed to be the same between Spain and the rest of the EMU.[10] We assume that the Calvo lotteries for wage setting imply average

[9]In Aspachs-Bracons and Rabanal (2010), we use standard Bayesian methods to estimate a dynamic stochastic general equilibrium (DSGE) model similar to the one presented here for Spain and the rest of the EMU using data between 1995 and 2008.

[10]Assuming that durable prices are flexible does not change the qualitative results of our analysis. Aspachs-Bracons and Rabanal (2010) use information contained in survey evidence for the euro area, as explained in Fabiani et al. (2006), as priors.

durations of wage contracts of one year ($\theta_{C,W} = \theta_{D,W} = 0.75$) and we also assume full indexation to last period's inflation, given the way wage contracts are set in Spain.[11] Finally, we also calibrate the parameters of the Taylor rule according to the estimates in our companion paper.

4.1 Impulse Response Functions

In this section, we discuss the main features of the model by presenting the impulse response functions of a monetary policy shock and a housing preference shock. We obtain the model's dynamics by taking a log-linear approximation around the steady state. In the appendix we detail the full set of linear equations of the model.

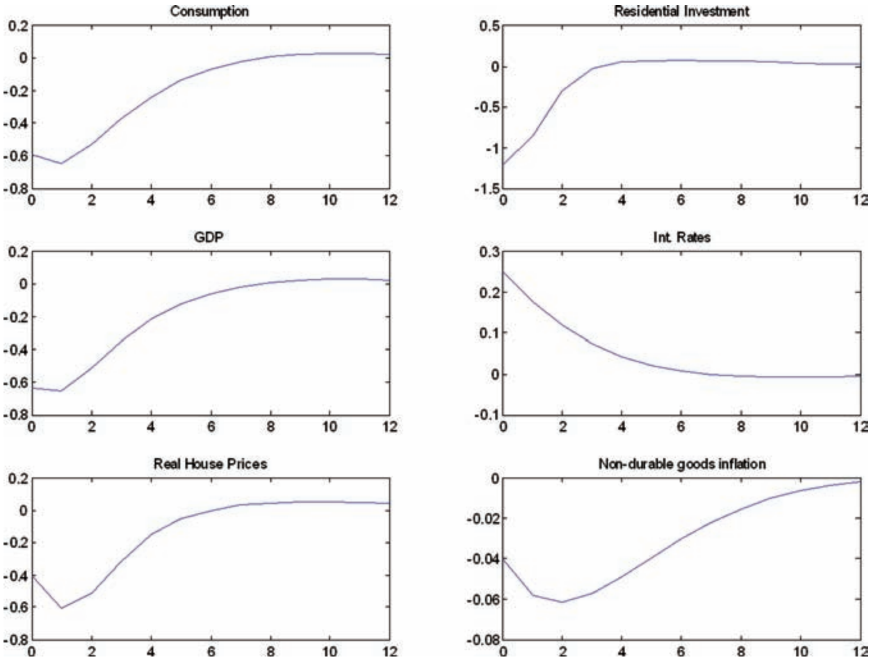
4.1.1 Monetary Policy Shock (ε_t^m)

Figure 8 presents the impulse response functions of the main variables in Spain to an expansionary monetary policy shock in the euro area. We choose the size of the shock ε_t^m in the Taylor-rule expression (33) to simulate an increase of 25 basis points on impact in the nominal interest rate. Following the shock, consumption of both good types declines. Similar to what we obtained in the VAR, the effect is quantitatively stronger in the durable sector, although we have trouble matching the long lags in the transmission mechanism present in the data. Note that we obtain a strong co-movement between both sectors even though the degrees of nominal rigidity in price setting are different across sectors. Why is this the case? After a monetary policy tightening, and in response to lower demand, durable goods producers can decrease prices faster than the non-durable producers and, hence, the relative price between durables and non-durables decreases (just as in the VAR-based evidence). Wage stickiness limits the degree to which real unit labor costs differ across sectors and, hence, the movement in relative prices is lower even under asymmetric nominal rigidities in price setting.[12] In addition, costly labor

[11] Smets and Wouters (2003) obtain a posterior mean of 0.66 for backward-looking wage indexation in the euro area. Using this paramter value instead of full indexation does not change the results.

[12] Di Ceccio (2009) finds a similar result in a two-sector real business-cycle model.

Figure 8. Impulse Response to Monetary Policy Shock



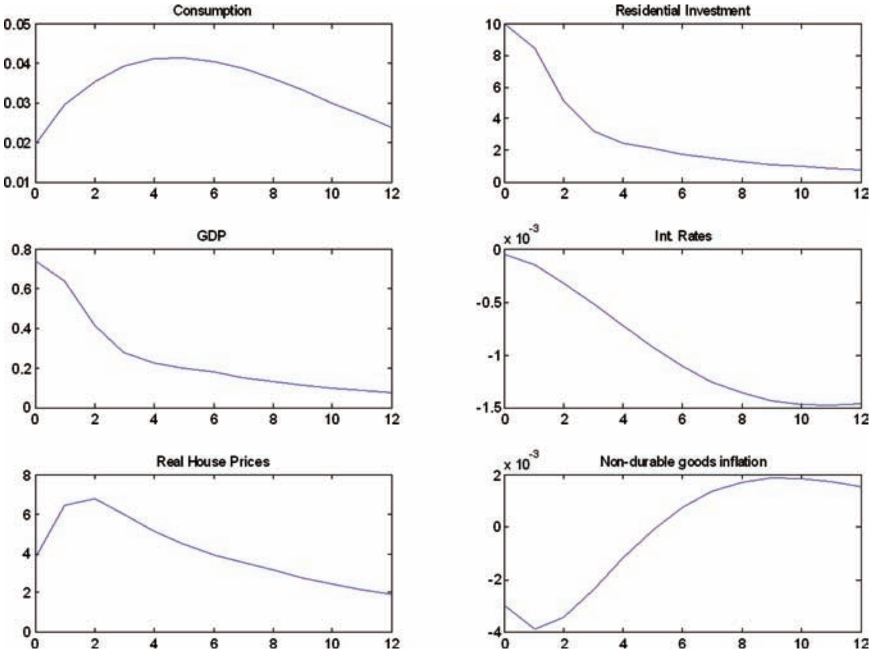
Notes: X-axis shows quarters after shock. Y-axis shows percent deviation from steady-state values.

reallocation limits the degree to which sectorial output can differ due to different labor inputs. Hence, as we discuss in the following section, labor market and wage rigidities are key to explaining the data.

4.1.2 Housing Preference Shock (ξ_t^D)

Next, we examine the effects of a housing preference shock in figure 9. In their study of the U.S. economy, Iacoviello and Neri (2010) conclude that these types of shocks explain a significant fraction of the volatility of house prices and residential investment. Darracq-Parriès and Notarpietro (2008) reach a similar conclusion when looking at euro-area data, and Aspachs-Bracons and Rabanal (2010) find a similar result when using data for Spain and the euro area. In the

Figure 9. Impulse Response to a Housing Preference Shock



Notes: X-axis shows quarters after shock. Y-axis shows percent deviation from steady-state values.

context of our model, one could see these demand pressures as stemming from population changes: increased immigration, the "baby boom" generation that in Spain peaked in the 1970s, and changes in social attitudes that reduce the number of persons per households and increase the number of household units.

The housing demand shock is normalized such that residential investment increases about 10 percent above its long-run value, and the shock has an AR(1) coefficient of 0.9. The preference shock in the durables sector also leads to an increase in the relative price of durables. Given the small size of the Spanish economy with respect to the euro area, interest rates barely react to developments in the Spanish economy, allowing it to experience a long-lived expansion in this sector. Note also that non-durable output slightly increases with the housing demand shock, which coincides with the VAR evidence presented above. However, as in Iacoviello and Neri (2010), the positive response of non-durable consumption is quantitatively small. In the following subsection, we seek to understand which mechanism in the model generates the co-movement between the two sectors.

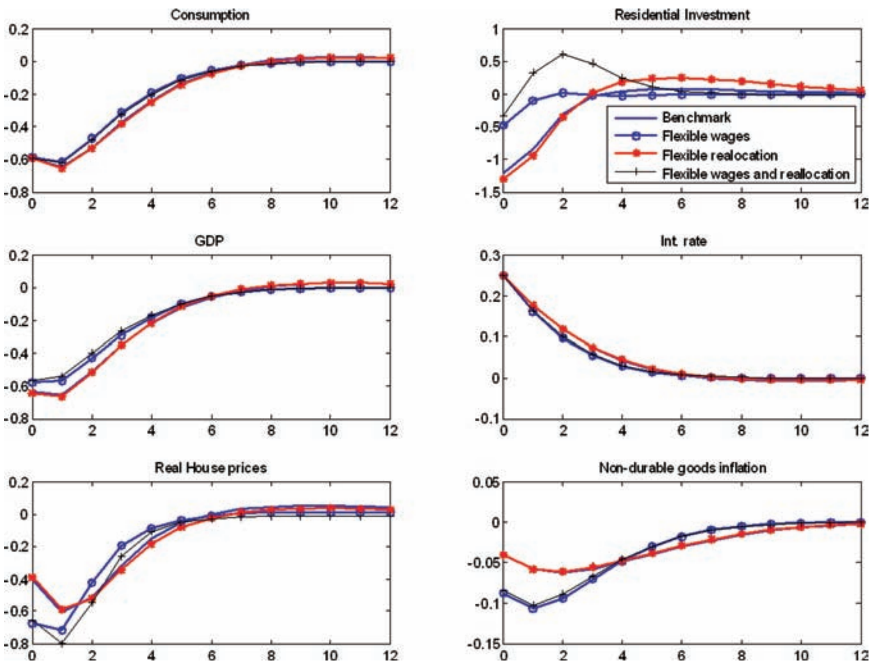
5. Robustness Checks

As argued by Carlstrom and Fuerst (2006) and Monacelli (2009), if prices are flexible in one sector but sticky in the other, then a monetary policy contraction will imply that output falls in the sticky-price sector but will increase in the flexible-price sector, contradicting VAR evidence using U.S. data. These papers suggest that introducing credit constraints and/or labor market rigidities might help solve the co-movement problem even under heterogeneous degrees of nominal rigidity. Hence, in this section we study how the impact of monetary and demand shocks changes for different degrees of labor market rigidities and financial frictions in the context of our model. The key to explaining the VAR evidence is the lack of flexibility in the labor market. This is crucial when there are sector-specific shocks.

5.1 The Role of Labor Market Frictions

In figures 10 and 11 we plot how the effect of both shocks changes as we remove wage stickiness and indexation in both sectors (by setting $\theta_{C,W} = \theta_{D,W} = \phi_{C,W} = \phi_{D,W} = 0$), and the degree of labor market reallocation (by setting $\iota_L = 0$). When we remove a rigidity, we do so for both countries. The first result to note is that we do not find lack of co-movement under a monetary policy shock. Even when both types of rigidities are eliminated—i.e., wages are allowed to be fully flexible and the work force can be reallocated instantaneously across sectors—non-durable output and durable output decrease after a monetary policy tightening. Sticky wages are key to explaining the fact that residential investment reacts more strongly than non-durable consumption to a monetary policy shock. When there are no labor market rigidities, real house prices experience a larger decline, and this tends to push demand for housing upward

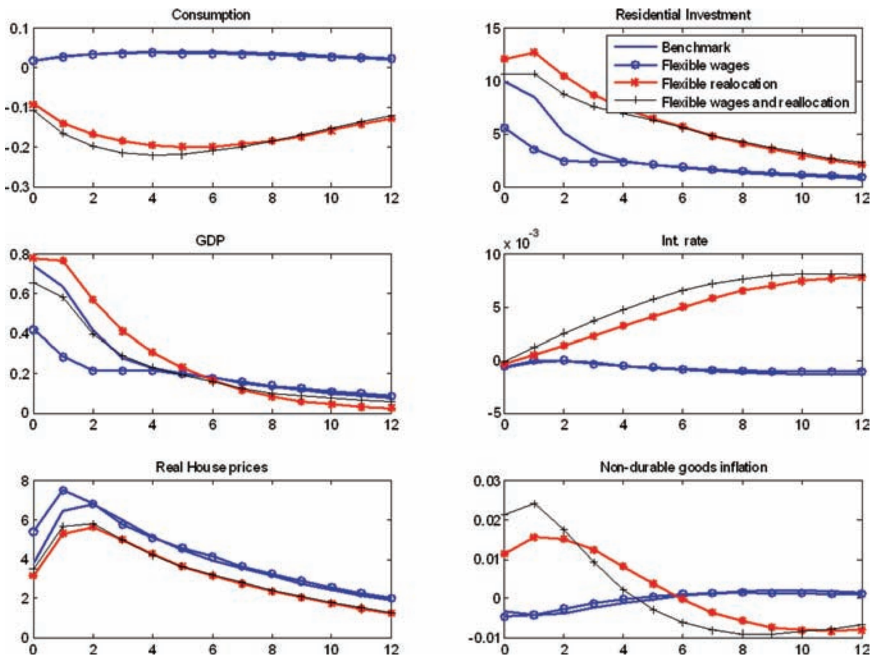
Figure 10. Impulse Response to a Monetary Shock: The Role of Labor Market Frictions



because (i) housing becomes cheaper and (ii) it is expected to appreciate from a low level. By limiting the variability in real unit labor costs across sectors and hence the relative price differential, wage stickiness helps in lowering the response of residential investment and helps explain its higher sensitivity to interest rate changes. But it does not affect the co-movement properties of the model. Given that the shock symmetrically affects both sectors, the introduction of labor market reallocation rigidities does not affect the results in an important way.

On the other hand, since the housing preference shock is asymmetric by nature, the model needs the labor market reallocation rigidities to explain the VAR evidence. In figure 11, we still calibrate the shock to deliver a 10 percent increase of residential investment under the benchmark calibration. We keep the same size of the shock as we change features of the model. When the workforce is allowed

Figure 11. Impulse Response to a Housing Preference Shock: The Role of Labor Market Frictions



to be reallocated instantaneously after the shock, non-durable output decreases while durable output increases by a larger amount, making it impossible to explain co-movement. Wage stickiness helps in increasing the persistent response of the endogenous variables to the shocks, but it does not affect the co-movement properties of the model under housing demand shocks. Therefore, the conclusion to this subsection is that each rigidity (wage stickiness and costly labor reallocation) helps explain the co-movement between consumption and residential investment to a different type of shock. Hence, both rigidities are needed.

5.2 The Effects of Financial Frictions

An important reason for concern for policymakers is the accelerator effect associated with fluctuations in housing prices. The nominal (and real) growth of the housing sector increases the amount of collateral available, allowing households to borrow more (or to save less in other instruments), and hence stimulates consumption. There is a well-established literature that highlights the role of collateral as a key element in the amplification in the transmission mechanism of shocks through business investment (see Kiyotaki and Moore 1997; and Bernanke, Gertler, and Gilchrist 1999). More recently, a new strand of the literature has focused on the role of residential investment in the transmission mechanism (see Aoki, Proudman, and Vlieghe 2004; Iacoviello 2005; Iacoviello and Neri 2010; and Monacelli 2009). We therefore proceed with our analysis by studying how the impact of each shock changes when the fraction of credit-constrained agents increases and/or their borrowing capacity changes.

To evaluate the importance of financial frictions, we analyze how the impact of a monetary policy shock and a housing preference shock varies as the fraction of agents with limited borrowing capacity increases and their pledging capacity changes. We extend the model of section 3 by assuming that a fraction $1-\lambda$ of agents face credit constraints. In particular, we assume that these agents, which are typically labeled as *borrowers* in the literature (see Monacelli 2009), are more impatient than the regular agents, whose mass is λ, and that now we label as *savers*.

We denote all variables for borrowers with a superscript B.

$$E_0\left\{\sum_{t=0}^{\infty}\beta^{B,t}\left[\gamma\log\left(C_t^{B,j}-\varepsilon C_{t-1}^{B}\right)\right.\right.$$
$$\left.\left.+(1-\gamma)\xi_t^D\log\left(D_t^{B,j}\right)-\frac{\left(L_t^{B,j}\right)^{1+\varphi}}{1+\varphi}\right]\right\},$$

where all the indices of consumption and hours worked, and the law of motion of the housing stock are the same as for the case of savers. Note that borrowers are more impatient and discount the future at a lower rate: $\beta^B<\beta$. Their budget constraint in nominal terms is given by

$$P_t^C C_t^{B,j}+P_t^D I_t^{B,j}+\tilde{R}_{t-1}S_{t-1}^{B,j}\leq S_t^{B,j}+\frac{W_t^C L_t^{B,C,j}}{X_t^C}+\frac{W_t^D L_t^{B,D,j}}{X_t^D}. \tag{36}$$

While borrowers can invest in housing, they do not own land as savers do. Also, borrowers do not have access to international capital markets, and hence they obtain credit from savers, who can trade in international bonds subject to an interest rate differential, just as in section 3. Borrowers face a collateral constraint that is tied to the current value of durable goods (i.e., the housing stock they own):

$$S_t^{B,j} \leq (1 - \chi) D_t^{B,j} P_t^D. \tag{37}$$

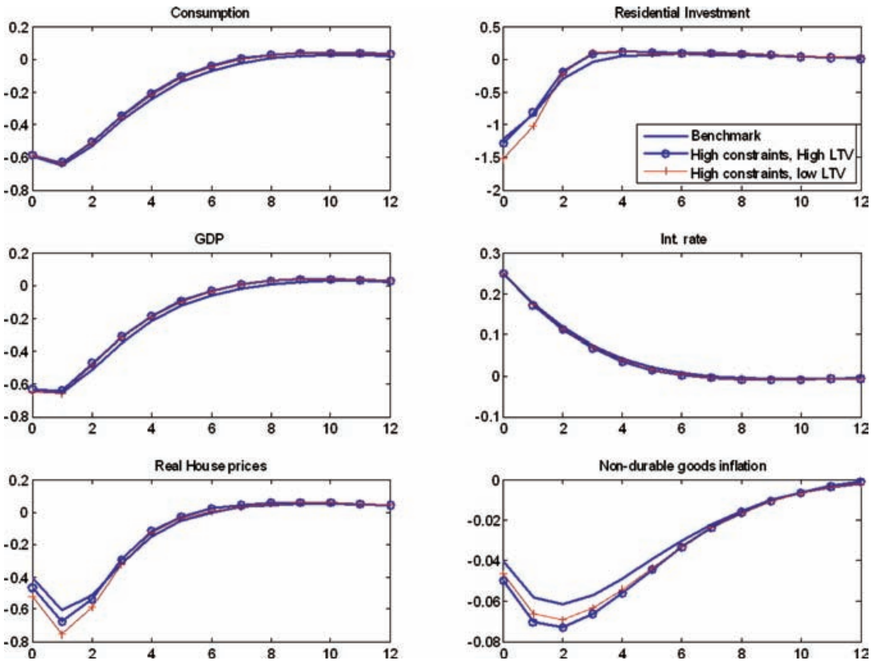
One can interpret the fraction χ as a downpayment rate, and hence $(1-\chi)$ is the loan-to-value (LTV) ratio. When house prices increase, borrowers are able to borrow more in order to finance additional durable and non-durable consumption.[13]

We present the impact effect of monetary and housing demand shocks as a function of λ and χ in figures 12 and 13. All other parameter values are set to those in table 2. We study an economy where $\lambda = 0.5$ and that includes two levels of indebtedness of borrowers: a low level ($\chi = 0.5$, corresponding to an LTV ratio of 50 percent) and a high level ($\chi = 0.1$, which implies an LTV of 90 percent). We obtain similar results to those reported in the existing literature: the responses of both non-durables and durables consumption are larger when financial frictions are tighter. By financial frictions being tighter we mean that there is a larger fraction of credit-constrained agents (lower λ) in the economy and/or their borrowing capacity is more restricted (higher χ).

After a monetary policy shock, the response of non-durable consumption does not appear to be sensitive to different levels of financial frictions. The effects on residential investment are more important, especially to different specifications of the LTV, $1 - \chi$. The tighter the credit conditions (lower LTV), the larger is the response of durable output to a monetary contraction. The conclusions are similar when we analyze the housing preference shock. The response of consumption is barely affected by the presence of financial frictions, especially when agents can borrow against it, but the numerical differences are very small when comparing the response of non-durable consumption to residential investment. The tightness of

[13] In an appendix available upon request, we detail the full set of log-linearized equations.

Figure 12. Impulse Response to a Monetary Shock: The Role of Financial Frictions

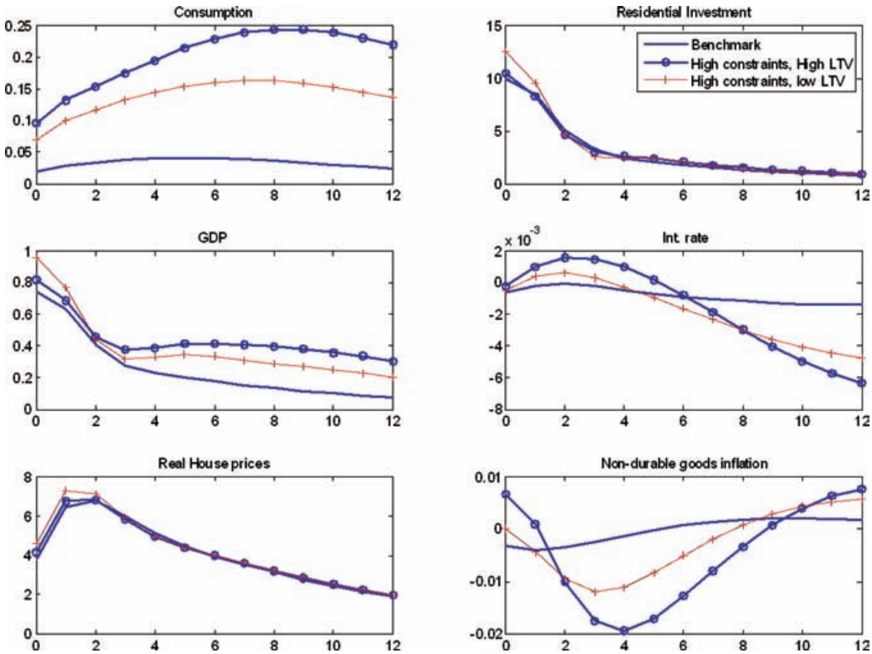


credit conditions implicit in the LTV ratio affects the response of durable output, while the fraction of constrained agents in the economy does not appear to play a major role in amplifying the shock.

Overall, even if financial frictions seem to amplify the monetary and preference shocks, their quantitative effects are rather small when compared with a model with homogeneous agents and no credit constraints (but with labor market frictions). In Aspachs-Bracons and Rabanal (2010) we estimated that the fraction of financially constraints individuals in the Spanish economy was low and it did not improve model fit. In the same spirit, Darracq-Parriès and Notarpietro (2008) have difficulty identifying the fraction of credit-constrained individuals in a DSGE model of the euro area, and show that this extension does not improve model fit.

This does not mean credit constraints are not present in the Spanish or EMU data. But they need to be modeled in a different way than has been included in the literature since Iacoviello (2005).

Figure 13. Impulse Response to a Housing Preference Shock: The Role of Financial Frictions



One avenue to study would be to allow agents to borrow against their labor income, in addition to housing collateral.

6. The Effects of Belonging to the EMU

The tools available to Spanish policymakers to react to shocks were reduced substantially when Spain joined the EMU. To analyze the consequences of having abandoned monetary policy independence, we extend the model of section 3 by assuming that both countries can run their own monetary policy with different national currencies as units of account.[14] We therefore introduce Taylor rules for both countries (Spain and an EMU without Spain) and an uncovered

[14]Of course, the model abstracts from other potential benefits of joining a monetary union, like the disappearance of exchange rate risk and the lowering of risk premia.

interest rate parity condition, and we assume producer currency pricing for imports and exports of non-durable goods, as in Lubik and Schorfheide (2006). The goal is to study the reaction of a small open economy in a two-country model when faced with housing demand shocks. It is important to note that this paper studies the 1996–2007 period, and the exercise only focuses on the possible costs of not being able to address demand-specific shocks in the sector or country using monetary policy. Our model does not evaluate other important costs of not belonging to the EMU, such as those associated with exchange rate volatility (e.g., higher domestic interest rates and lower international trade), which could affect growth.

In log-linear terms, the uncovered interest rate parity reads as follows:

$$r_t - r_t^* = E_t ner_{t+1} - ner_t - \kappa b_t, \tag{38}$$

where ner_t is the (log-deviation from the steady state) of the nominal exchange rate, defined as units of home country currency per unit of foreign country currency. This equation links the interest rate differential to the expected depreciation of the currency and also includes the endogenous risk premium depending on the net foreign asset position as percent of GDP of the economy (b_t).

In this case, the domestic interest rate becomes r_t, while the foreign interest rate is r_t^*, and both follow Taylor rules targeting domestic CPI inflation:

$$r_t = \gamma_R r_{t-1} + (1-\gamma_R)\gamma_\pi \Delta p_t^C + (1-\gamma_R)\gamma_D \Delta p_t^D \tag{39}$$

$$r_t^* = \gamma_R^* r_{t-1}^* + \left(1-\gamma_R^*\right)\gamma_\pi \Delta p_t^{C^*}. \tag{40}$$

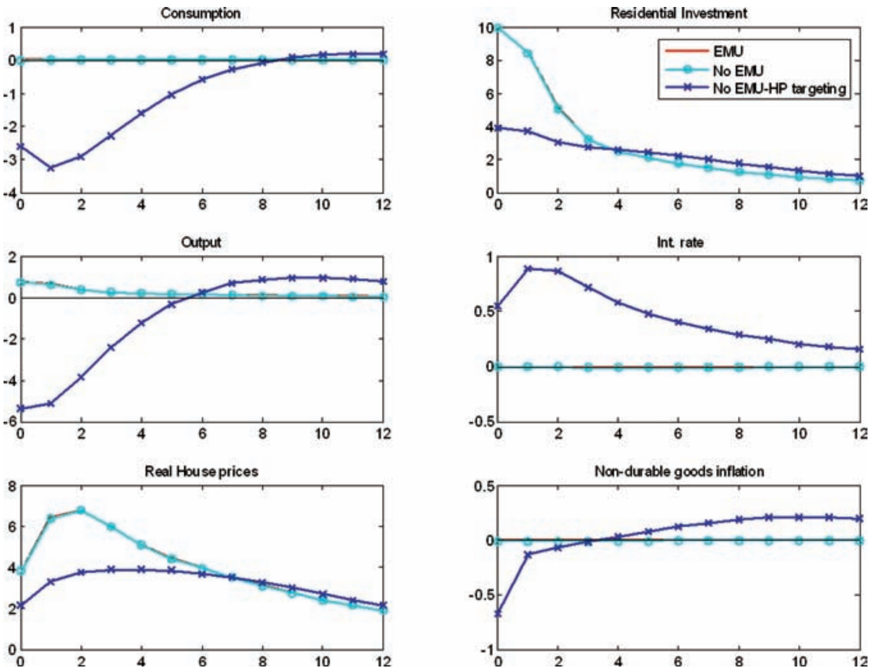
Note that we assume that the coefficients of the Taylor rule (γ_R and γ_π) are the same across countries. In addition, we consider that the home country can either run a strict inflation-targeting regime ($\gamma_D = 0$) or react to deviations in the durable price inflation rate, $\gamma_D > 0$.

Finally, since we have assumed that there is producer currency pricing and that the law of one price holds, non-durables inflation in both countries is given by

$$\Delta p_t^C = \tau \Delta p_{H,t} + (1-\tau)(\Delta p_{F,t} + \Delta s_t) \tag{41}$$

$$\Delta p_t^{C^*} = (1-\tau^*)(\Delta p_{H,t} - \Delta s_t) + \tau^* \Delta p_{F,t} \tag{42}$$

Figure 14. Impulse Response to Housing Preference Shock: The Effects of Belonging to the EMU



Notes: X-axis shows quarters after shock. Y-axis shows percent deviation from steady-state values.

such that movements in the nominal exchange rate affect directly the price of imports and exports.

6.1 Impulse Response from the Model

In figure 14 we compare the impulse response functions of a housing demand shock under a fixed exchange rate, a pure floating inflation-targeting regime and a pure floating regime with housing inflation targeting. We use the same calibrations discussed in table 2. When we refer to the "No EMU" we set the parameter $\gamma_D = 0$, while in the "No EMU-HP targeting" we set the parameter $\gamma_D = 0.5$. We have also studied the case in which the Spain Taylor rule targets the nominal exchange rate, which results in an intermediate case between joining the EMU and running strict inflation targeting.

Under a housing demand shock of the same size, the response of output is almost the same whether Spain belongs to the EMU or not. The small impact of this shock into the euro-area economy produces no reaction from the monetary authority, and the Spanish economy experiences high growth rates in the durable sector, while the non-durable sector barely reacts, and CPI-inflation does not change either. This explains why the response of the main variables is almost the same because the difference in the CPI inflation paths does not justify a stronger reaction from the monetary authority outside the EMU.

Finally, we analyze the implications of having a monetary authority that reacts not only to CPI inflation but also to deviations in housing prices. The rationale for this case is that we assume that the hypothetical monetary policy in Spain would try to "lean against the wind" when faced with increasing house prices. After a housing demand shock, inflation in the durable sector increases. Therefore, the response of the monetary authority in this case consists of increasing interest rates, which reduces non-durable consumption and residential investment, and CPI inflation. Nominal house prices decline but real house prices increase. The collapse in non-durable consumption comes from two channels. The first channel is higher interest rates, and the second is the nominal exchange rate appreciation that comes with higher interest rates.

Therefore, the monetary policy trade-off is the following: to offset the effects of a housing demand shock, a recession in the non-durable sector of the economy is necessary, a politically unacceptable consequence to many central banks. To the extent that these reduced-form demand shocks are capturing other developments in the credit or housing markets (for instance, lax credit practices or tax breaks for homeownership), using another tool directed at those imperfections would be better than having monetary policy address these distortions directly.

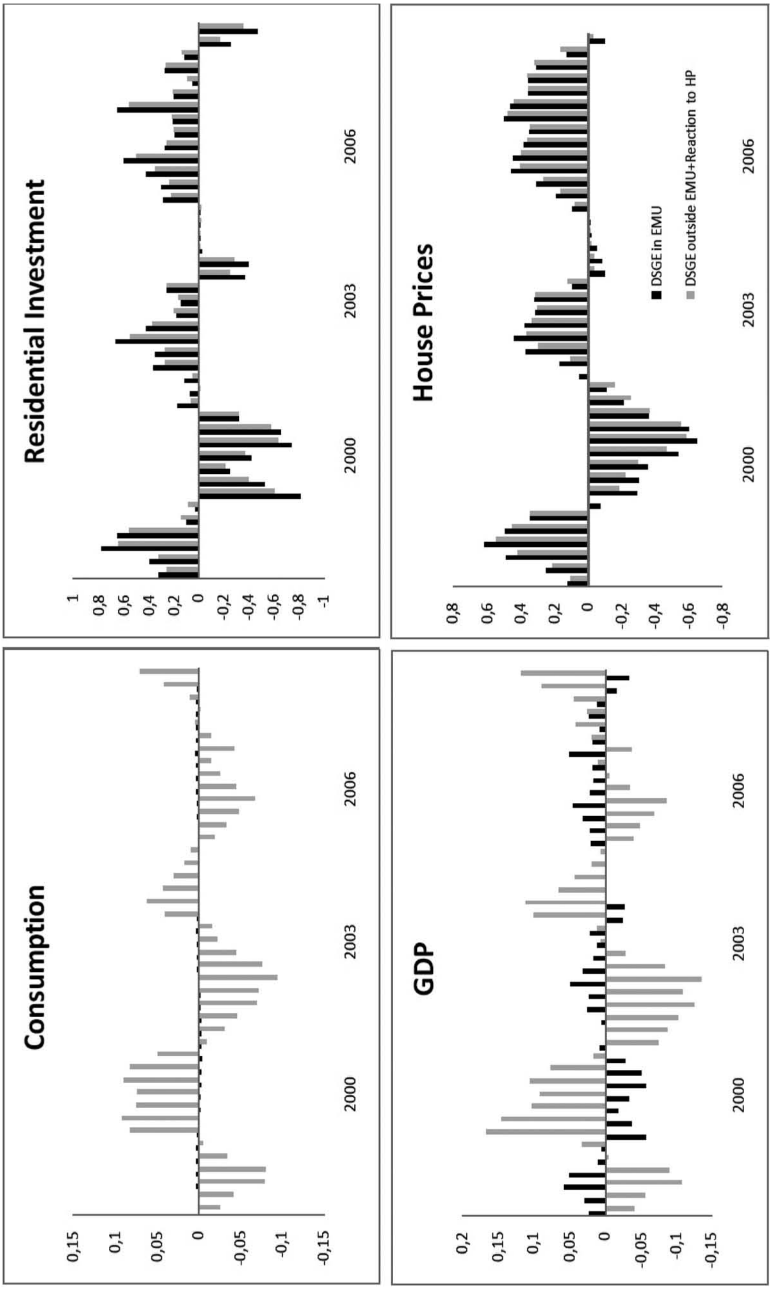
6.2 Counterfactual Simulation of the Model

After having shown the different impulse responses of the economy to housing demand shocks depending on the monetary policy regime, this subsection performs a somewhat related exercise. The time series of housing demand shocks is obtained from the VAR using the Cholesky decomposition, and the shocks are fed into the DSGE model. Actually, the shocks are the same as the ones used in the historical decomposition in section 2.4. Then, we analyze the role of the different policy rules, including the counterfactual where Spain was outside the EMU. Figure 15 shows the results. The black bar shows the behavior of the model with a currency union with the rest of the EMU. Housing demand shocks mostly have an effect on residential investment and house prices, and they also spill over to consumption and real GDP, although the effect is quantitatively much smaller, as was shown in the VAR section. The gray bar shows what happens under the counterfactual where Spain is outside the euro and the central bank reacts to house prices. The monetary authorities cannot do much to reduce the volatility of the housing variables (prices and investment), even when they "lean against the wind." On the other hand, the volatility of output and consumption increases when the central bank reacts to house price fluctuations under house price demand shocks. In downturns, reacting to house prices is desirable, as it stimulates the economy. But in the upturns, it leads to the opposite effect and can put the economy into a recession. So overall, it is not desirable to react to house prices because doing so increases volatility.

7. Concluding Remarks

In this paper we have studied the recent evidence on interest rates, housing prices, and residential investment in Spain. We have presented some evidence based on a VAR model, and have rationalized our findings with a two-country, two-sector model with housing demand and monetary shocks. One important caveat to the VAR evidence is that the sample period for the VAR only includes a decade of data during a period of transition, and hence the empirical analysis may be subject to non-trivial small-sample bias—an issue recently emphasized by Chari, Kehoe, and McGrattan (2008). Perhaps one direction for further research would be to use artificial data drawn from stochastic simulations of the DSGE model in order to obtain a rough gauge of the small-sample properties of the empirical analysis.

Figure 15. Counterfactual Simulation of the Model



We have also examined the key features of the model in order to help explain the results. Of all the mechanisms suggested in the literature, labor market rigidities are necessary to obtain the right co-movement between the two sectors of the economy. The introduction of financial frictions helps in increasing the response of non-durable goods consumption to both shocks, but this increase can also be achieved under other modeling assumptions. The model is linearized around a steady state, assuming no imbalances in trade or the current account. While this approach simplifies the analysis considerably, it does seem to be an important departure from reality. Future research regarding the implications of linearizing the model around a qualitatively different steady state should be considered.

We have studied the cost of losing monetary autonomy (i.e., through currency union membership). We conclude that the behavior of the Spanish economy under its own monetary policy or under euro membership does not change the outcome to a housing demand shock due to the following reason: even if the shock has important effects on residential investment and house prices, Spanish CPI inflation does not change, and hence an inflation-targeting monetary authority remains passive in either case. However, if the Spanish monetary authority reacts to housing price changes, the response of the main variables differs substantially, with high costs in the non-durable sector: non-durable output suffers an important and persistent contraction. Hence, it is not clear at all that if Spain had not belonged to the EMU the boom-and-bust cycle in housing prices between 1996 and 2007 could have been avoided by using monetary policy.

The case of other advanced economies provides additional evidence to support this argument. Dokko et al. (2009) and Fatás et al. (2009) study the relationship between the stance of monetary policy (proxied by Taylor-rule residuals) and real house price increases during 2002–06. Both studies find that the cross-country relationship between the two variables is statistically weak. Both studies single out the case of Spain, where monetary policy was about 300 basis points on average below the prescriptions of a standard Taylor rule, and house prices appreciated about 80 percent. But both studies also mention the cases of the United Kingdom, New Zealand, and Australia where monetary policy was not loose and yet the housing price boom was sizable.[15] Finally, Dokko et al. (2009) provide simulations based on the FRB/US model and conclude, as we have shown in this paper, that monetary policy tightening would likely only have marginal effects in containing a house price bubble and might well be detrimental to other sectors of the economy.

Appendix. Linear Approximation

Here we present the log-linear conditions. Also, we define the relative price of durables in terms of non-durables as $Q_t = \frac{P_t^D}{P_t^C}$, and the terms of trade as $T_t = \frac{P_{F,t}}{P_{H,t}}$. Also, ω_t^i denotes deviations from the real wage from steady-state values, defined as nominal wage (W_t^i) divided by the CPI (P_t^C), for $i = C, D$.

From the optimal decisions by savers we get the following:

$$q_t - \frac{c_t - \varepsilon c_{t-1}}{1 - \varepsilon} + \psi(i_t - i_{t-1}) = \mu_t + \beta\psi(E_t i_{t+1} - i_t), \tag{43}$$

where $\psi = S''(.)$.

$$[1 - \beta(1 - \delta)](\xi_t^D - d_t) = \mu_t - \beta(1 - \delta)E_t\mu_{t+1} \tag{44}$$

$$q_t = q_{t-1} + \Delta p_t^D - \Delta p_t^C \tag{45}$$

$$\varepsilon\Delta c_t = E_t\Delta c_{t+1} - (1 - \varepsilon)\big(\tilde{r}_t - E_t\Delta p_{t+1}^C\big) \tag{46}$$

Under Calvo wage setting and with partial indexation to past non-durable (CPI) inflation (with coefficients $\varphi_{C,W}$ and $\varphi_{D,W}$), the wage-setting equations can be log-linearized into to the following wage Phillips curves:

[15] In this context, it might be interesting to note the position of the newly elected government in the United Kingdom, which is inclined to incorporate housing prices in a comprehensive measure of consumer prices. In his letter of May 18, 2010 to the Governor of the Bank of England, the Chancellor of the Exchequer George Osborne mentioned that "As we have discussed, over the longer term I would welcome your views on how we might accelerate the process of including housing costs in the CPI inflation target." The letter is available at www.hm-treasury.gov.uk/ukecon_mon_index.htm.

$$\begin{aligned}
&\omega_t^C - \omega_{t-1}^C + \Delta p_t^C - \varphi_{C,W}\Delta p_{t-1}^C \\
&= \beta E_t\big(\omega_{t+1}^C - \omega_t^C + \Delta p_{t+1}^C - \varphi_{C,W}\Delta p_t^C\big) \\
&\quad + \kappa^{C,W}\left[\frac{c_t - \varepsilon c_{t-1}}{1-\varepsilon} + [(\varphi-\iota)\alpha + \iota]l_t^C + (\varphi-\iota)(1-\alpha)l_t^D - \omega_t^C\right],
\end{aligned} \tag{47}$$

where $\kappa^{C,W} = \frac{(1-\theta_{C,W})(1-\beta\theta_{C,W})}{\theta_{C,W}}$, and

$$\begin{aligned}
&\omega_t^D - \omega_{t-1}^D + \Delta p_t^C - \varphi_{D,W}\Delta p_{t-1}^C \\
&= \beta E_t\big(\omega_{t+1}^D - \omega_t^D + \Delta p_{t+1}^C - \varphi_{D,W}\Delta p_t^C\big) \\
&\quad + \kappa^{D,W}\left[\frac{c_t - \varepsilon c_{t-1}}{1-\varepsilon} + [(\varphi-\iota)(1-\alpha) + \iota]l_t^D + (\varphi-\iota)\alpha l_t^C - \omega_t^D\right],
\end{aligned} \tag{48}$$

where $\kappa^{D,W} = \frac{(1-\theta_{D,W})(1-\beta\theta_{D,W})}{\theta_{D,W}}$.

The relationship between the domestic and the EMU-wide interest rates is as follows:

$$\tilde{r}_t = r_t - \kappa\hat{b}_t, \tag{49}$$

where $\hat{b}_t = (B_t/Y_tP_t)$ denotes the deviation of foreign assets as percent of GDP from its steady-state value of zero.

The evolution of net foreign assets is

$$\hat{b}_t = \frac{1}{\beta}\hat{b}_{t-1} + \frac{(1-n)(1-\tau^*)}{n}\big(c_{H,t}^* - t_t\big) - (1-\tau)c_{F,t}. \tag{50}$$

The evolution of domestic and imported non-durable consumption is

$$c_{H,t} = (1-\tau)t_t + c_t \tag{51}$$

$$c_{F,t} = -\tau t_t + c_t. \tag{52}$$

Here we list the evolution of the foreign country variables for households:

$$q_t^* - \frac{c_t^* - \varepsilon c_{t-1}^*}{1-\varepsilon} + \psi\big(i_t^* - i_{t-1}^*\big) = \mu_t^* + \beta\psi\big(E_t i_{t+1}^* - i_t^*\big) \tag{53}$$

$$[1-\beta(1-\delta)](\xi_t^{D^*} - d_t^*) = \mu_t^* - \beta(1-\delta)E_t\mu_{t+1}^* \tag{54}$$

$$q_t^* = q_{t-1}^* + \Delta p_t^{D^*} - \Delta p_t^{C^*} \tag{55}$$

$$\varepsilon \Delta c_t^* = E_t \Delta c_{t+1}^* - (1-\varepsilon)\big(r_t - E_t \Delta p_{t+1}^{C^*}\big) \tag{56}$$

$$\begin{aligned}
&\omega_t^{C^*} - \omega_{t-1}^{C^*} + \Delta p_t^{C^*} - \varphi_{WC} \Delta p_{t-1}^{C^*} \\
&= \beta E_t \big(\omega_{t+1}^{C^*} - \omega_t^{C^*} + \Delta p_{t+1}^{C^*} - \varphi_{C,W} \Delta p_t^{C^*}\big) + \kappa^{C,W} \Bigg[\frac{c_t^* - \varepsilon c_{t-1}^*}{1-\varepsilon} \\
&\quad + [(\varphi^* - \iota^*)\alpha^* + \iota^*] l_t^{C^*} + (\varphi^* - \iota^*)(1-\alpha^*) l_t^{D^*} - \omega_t^{C^*}\Bigg]
\end{aligned} \tag{57}$$

$$\begin{aligned}
&\omega_t^{D^*} - \omega_{t-1}^{D^*} + \Delta p_t^{C^*} - \varphi_{D,W} \Delta p_{t-1}^{C^*} \\
&= \beta E_t \big(\omega_{t+1}^{D^*} - \omega_t^{D^*} + \Delta p_{t+1}^{C^*} - \varphi_{D,W} \Delta p_t^{C^*}\big) + \kappa^{D,W} \Bigg[\frac{c_t^* - \varepsilon c_{t-1}^*}{1-\varepsilon} \\
&\quad + [(\varphi^* - \iota^*)(1-\alpha^*) + \iota^*] l_t^{D^*} + (\varphi^* - \iota^*)\alpha^* l_t^{C^*} - \omega_t^{D^*}\Bigg],
\end{aligned} \tag{58}$$

where $\kappa^{C,W}$ and $\kappa^{D,W}$ are the same as in the home country. The demand for foreign and domestic goods is

$$c_{H,t}^* = \tau^* t_t + c_t^* \tag{59}$$

$$c_{F,t}^* = -(1-\tau^*) t_t + c_t^*, \tag{60}$$

where we have used the definition of the terms of trade, the fact that $t_t = -t_t^*$, and the evolution of the terms of trade is given by

$$t_t = t_{t-1} + \Delta p_t^F - \Delta p_t^H. \tag{61}$$

The deflators of the final goods are

$$\Delta p_t = \gamma \Delta p_t^C + (1-\gamma) \Delta p_t^D \tag{62}$$

$$\Delta p_t^* = \gamma^* \Delta p_t^{C^*} + (1-\gamma^*) \Delta p_t^{D^*}, \tag{63}$$

where CPI inflation is given by

$$\Delta p_t^C = \tau \Delta p_{H,t} + (1-\tau) \Delta p_{F,t} \tag{64}$$

$$\Delta p_t^{C^*} = (1-\tau^*) \Delta p_{H,t} + \tau^* \Delta p_{F,t}. \tag{65}$$

The production functions are given by

$$y_t^C = l_t^C \tag{66}$$

$$y_t^D = \alpha^D l_t^D \tag{67}$$

$$y_t^{C^*} = l_t^{C^*} \tag{68}$$

$$y_t^{D^*} = \alpha^D l_t^{D^*}. \tag{69}$$

And the pricing equations are given by

$$\Delta p_t^H - \varphi_C \Delta p_{t-1}^H = \beta E_t\left(\Delta p_{t+1}^H - \varphi_C \Delta p_t^H\right) + \kappa^C\left[\omega_t^C + (1-\tau)t_t\right], \tag{70}$$

where $\kappa^C = \frac{(1-\theta_C)(1-\beta\theta_C)}{\theta_C}$, and

$$\Delta p_t^D - \varphi_D \Delta p_{t-1}^D = \beta E_t(\Delta p_{t+1}^D - \varphi_D \Delta p_t^D) + \kappa^D\left[\omega_t^D + (1-\alpha^D)l_t^D - q_t\right], \tag{71}$$

where $\kappa^D = \frac{(1-\theta_D)(1-\beta\theta_D)}{\theta_D}$.

For the foreign country, after assuming symmetric Calvo parameters, we get that

$$\Delta p_t^F - \varphi_C \Delta p_{t-1}^F = \beta E_t\left(\Delta p_{t+1}^F - \varphi_C \Delta p_t^F\right) + \kappa^C\left[\omega_t^{C^*} - (1-\tau^*)t_t\right] \tag{72}$$

$$\Delta p_t^{D^*} - \varphi_D \Delta p_{t-1}^{D^*} = \beta E_t\left(\Delta p_{t+1}^{D^*} - \varphi_D \Delta p_t^{D^*}\right) + \kappa^D\left[\omega_t^{D^*} + (1-\alpha^D)l_t^{D^*} - q_t^*\right]. \tag{73}$$

The market clearing conditions for the goods sectors read as follows:

$$y_t^C = \tau c_{H,t} + \frac{(1-n)(1-\tau^*)}{n} c_{H,t}^* \tag{74}$$

$$y_t^{C^*} = \tau^* c_{F,t}^* + \frac{n(1-\tau)}{1-n} c_{F,t} \tag{75}$$

$$d_t = (1-\delta)d_{t-1} + \delta y_t^D \tag{76}$$

$$d_t^* = (1-\delta)d_{t-1}^* + \delta^* y_t^{D^*} \quad (77)$$

$$y_t^D = i_t \quad (78)$$

$$y_t^{D^*} = i_t^*, \quad (79)$$

while for the labor market they are

$$l_t^{tot} = \alpha l_t^C + (1-\alpha) l_t^D \quad (80)$$

$$l_t^{tot,*} = \alpha^* l_t^{C^*} + (1-\alpha^*) l_t^{D^*}. \quad (81)$$

To close the model, we specify a monetary policy Taylor rule conducted by the ECB:

$$r_t = \gamma_R r_{t-1} + (1-\gamma_R)\left(\Delta p_t^{EMU}\right) + \varepsilon_t^m, \quad (82)$$

where the euro-area CPI is given by

$$\Delta p_t^{EMU} = n\Delta p_t^C + (1-n)\Delta p_t^{C^*}. \quad (83)$$

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Discussion of "The Effects of Housing Prices and Monetary Policy in a Currency Union"

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1. Introduction

Central questions raised by recent experience are "why do housing prices fluctuate?" and "what should central banks do about it?" For member states of a currency union, such as Spain or Texas, independent monetary policy cannot be conducted, so that it is important to inquire whether fluctuating housing prices make currency union participation undesirable.

In this timely paper, Oriol Aspachs-Bracons and Pau Rabanal provide some useful insights into the nature of the Spanish experience, into the mechanics of a two-region dynamic stochastic general equilibrium (DSGE) model that contains a housing sector in each region, and on the differences between responses to various shocks under alternative policy rules. It is one component of the authors' recent work that contributes to a rapidly growing literature on housing and macroeconomics.

Since housing is a durable good, the authors draw on two relevant background literatures, each of which is New Keynesian in structure. In terms of the housing literature, the DSGE model analysis builds most directly on prior work by Iacoviello and Neri (2010), which constructs a closed-economy macroeconomic model with separate sectors for "final consumption" and "housing investment." In the housing literature, central questions are the response of housing investment, housing prices, final consumption, and aggregate output to shocks in monetary policy in housing demand. In terms of the durability literature, the DSGE model analysis is related to work by Barsky, House, and Kimball (2007), Monacelli (2009), and Sterk (2010) that also studies closed-economy models with separate sectors that are "non-durable" and "durable" in nature. In both housing and durability literatures, a variety of nominal frictions are examined, including wage and price stickiness. In both literatures, issues of co-movement are central, such as (i) do housing prices move with housing investment? and (ii) do sectoral outputs move together or inversely? Consequently, real frictions play an important role, in terms of the imperfect substitutability or costly reallocation of capital and labor across sectors. These two literatures also explore the role of financial market imperfections, such as the idea that some households have borrowing demands that are subject to collateral requirements as in Iavoviello and Neri (2010), Monacelli (2009), and Sterk (2010).

In addition to these elements, Aspachs-Bracons and Rabanal (henceforth, AR) explore a two-region model that features two differently sized regions and is designed to be applied to Spain and the euro area. Clearly, additional issues of co-movement arise in such a setting if a particular region is affected by shocks that are not occurring elsewhere.

The research strategy follows the path of Christiano, Eichenbaum, and Evans (1999) of estimating a small structural vector autoregression (SVAR) and calculating impulse responses to a subset of shocks, to which the result of a model economy is then compared. For AR's analysis of quarterly Spanish data, these are an interest rate shock—taken to the result of euro-area monetary policy—and a housing demand shock. The analysis is conducted over a historical period (1997 through 2010) during which there were major variations in housing investment, housing prices, mortgage borrowing, and the current account.[1] The DSGE model is of the broad family of small-scale operational monetary policy frameworks with agent optimization and many frictions, of which Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003) are leading contributions.

The organization of my comments is as follows. In section 2, I discuss some general aspects of the Spanish housing experience. In section 3, I discuss the results of the VAR estimation. In section 4, I consider the linkage between results in this paper and in the closed-economy analysis of Iacoviello and Neri (2010) that stresses housing market spillovers. In section 5, I briefly discuss the authors' conclusions about monetary policy.

[1]While the full monetary integration did not occur until 1999, the authors suggest that Spain effectively coordinated its interest rate policy with other euro-area countries starting in 1997.

2. The Spanish Experience

To a reader not knowledgeable about the Spanish experience, such as me, there is a lot of interesting information that is contained in figures 1 through 4. Throughout my discussion, when I refer to any particular figure such as figure 1, I will be considering the figure in the Aspachs-Bracons and Rabanal paper.

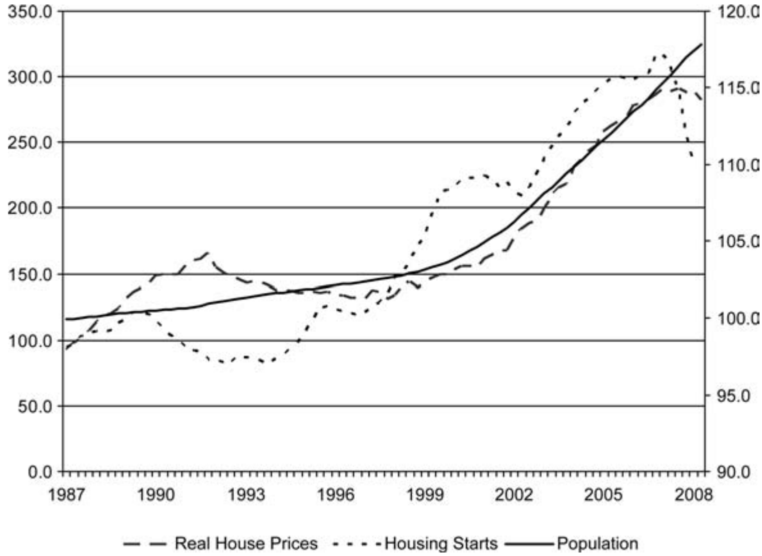
Importance to Real Aggregate Activity. To begin, these initial figures assure us that we are talking about something pretty important in terms of macroeconomics: as shown in figure 2, the boom was a major increase in housing investment relative to GDP (I^H/Y) during 1988 through 2005, with an increase from about 5 percent to about 9 percent. In 2006 through mid-2007, this ratio stayed at about the 9 percent level; then it declined dramatically to about 5 percent of GDP. In a simple accounting sense, if there was no change in any other sector, the housing boom led to a cyclical swing of 5 percent up and down.

Size of Housing Price Movements. Figure 1 shows that, starting in 1998, there was a surge in house prices that lasted through the end of 2007: in the middle of the period, housing price inflation exceeded 15 percent per year. The co-movement in figure 1 is broadly consistent with the hypothesis—which I associate with John Taylor (2007) for the United States—that loose monetary policy drove down the nominal interest rate and led to the housing boom, i.e., to a major increase in real housing prices. That is, there is a clear negative association between the level of the interest rate and the rate of change of house prices, starting in 1998 and continuing through 2008. Taylor's particular argument is that the U.S. policy rate was low during 2003–06, relative to the prediction of his benchmark rule, which cannot be directly evaluated from figure 1. But there is an evident decline in the one-year interbank rate and an acceleration of housing price inflation during 2001–05.

This rate-of-change information is not the same as the real housing price, which I would have preferred to see, so I went to a recent International Monetary Fund (IMF) report on the Spanish housing market.[2]

[2]The IMF Country Report No. 09/129 (April 2009) is available at www.imf.org/external/pubs/ft/scr/2009/cr09129.pdf.

Figure K1. Housing Prices and Housing Starts (Left Scale) and Population (Right Scale) Are Indices with 1987=100



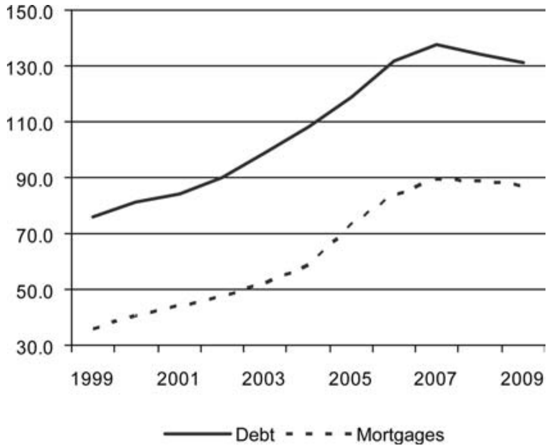
Source: IMF data courtesy of Pau Rabanal.

This figure—marked K1 so that it can be readily distinguished in the discussion below from the AR figures—shows the co-movement of real housing prices, housing starts, and population over 1987–2008. The AR sample period begins in 1996 and goes through 2009, so that there is substantial overlap. From my standpoint, when AR discuss housing price shocks, figure K1 suggests that they are right to focus on increasing population as one of the potential core drivers (they also discuss the related, reinforcing factor that the number of households per capita has been rising in Spain: see their figure 4 and related text).[3]

They also stress that there was a surge in mortgage credit. In their figure 3, credit relative to GDP jumps by about 20 percent

[3]It is also clear from their discussion that population variations involve potentially endogenous immigration responses, which complicates the interpretation of a figure like K1.

Figure K2. Total Debt and Mortgage Debt as Ratios to Spanish Disposable Income



Source: Supplied by Pau Rabanal based on data from Euro Stat and the Bank of Spain.

in the two years 2005–06. Looking again at developments along the lines outlined in the IMF report, shown as figure K2, mortgage credit relative to disposable income increases substantially during 2001–07: it dominates the rise in total debt, which moves from about 75 to 135 percent of disposable income. The developments are strongest in 2005–06 in figure K2 as well.

Putting these elements together, it looks like the major acceleration of mortgage lending occurred *after* the major acceleration of housing prices. Prices appear to lead lending, rather than the other way around. I don't think that this lag mechanism is present in their model, but it could be added at relatively low cost and its implications explored.

3. SVAR Results

The procedure of first estimating an SVAR with limited restrictions and then comparing DSGE and SVAR impulse responses is a natural strategy. It is modest in that the analyst does not impose a lot of structure on the empirical model and seeks only a partial identification, restricting attention to the response of the SVAR to a subset of structural shocks.

Specifically, AR estimate a vector autoregression in final private consumption, residential investment, real output (GDP), a three-month interest rate, and real housing prices. They order the variables as just indicated and assume that there is a lower triangular matrix B in a system of the form

$$Y_t = C + \sum_{l=1}^{L} A_l Y_{t-l} + B u_t,$$

where C is a vector of constants, A_l are lag coefficient matrices, and u_t are the shocks, only the last two of which are given a structural interpretation: (i) the shock to the interest rate, which can affect housing prices but has no other within-period effects; and (ii) the shock to housing prices, which is given a demand/preference shock interpretation.

3.1 What Do They Find?

Aspachs-Bracons and Rabanal report results on impulse responses and historical decompositions for their two identified shocks.

3.1.1 Monetary Shock

The impulse responses shown in figure 5 indicate that a 25-basis-point “monetary policy” shock to the short-term interest rate has a sustained effect on the level of the nominal interest rate for two to three years in duration, with a peak response of 40 basis points. The higher interest rate leads to a decline in housing prices and investment that begins within a year, with a trough response of 2 percent of investment and 2–3 percent of house prices that occurs in the second and third years. By contrast, the policy shock has a quite small effect on the level of consumption and output within a year, but there may be larger effects at the three-year horizon: these are estimated to be $-1/2$ percent for both consumption and output, although the confidence intervals are wide.

The historical decomposition of the 1998–2008 period provided in figure 7 suggests that monetary policy shocks played a role in the boom and bust of housing prices and investment, but a modest one.

3.1.2 House Price Shocks

The impulse responses to a housing price shock shown in figure 6 are quite suggestive. The shock has an essentially uniform positive impact at all horizons on prices, of about 10 percent. It stimulates an increase in investment that is initially modest, peaks at 30 percent, and then dies away. While the shock has little short-horizon effect on output and consumption, it leads to estimated impacts of about 1.5 percent in each. Potentially, this might be the effect of news about permanent income, mitigated by frictions which slow down the impact of it.

3.1.3 How Do They Use the SVAR?

Aspachs-Bracons and Rabanal use the SVAR essentially to determine the sign and relative size of various responses which their model should capture. They do not take the longer-run empirical dynamics as a target.

4. Assessing Housing Spillovers

I like the fact that Aspachs-Bracons and Rabanal show us how various model frictions contribute to producing differing responses of housing price and housing investment as well as other macroeconomic responses to the two shocks. A good bit of their analysis focuses on comparison with the closed-economy work on housing, by Iacoviello and Neri (2010), so that my discussion will also consider this comparison.

Iacoviello and Neri (2010) argue that there are important "spillovers" from the housing market into consumption, but not on investment of a business form. By contrast, AR conclude in section 5 that "the response of non-durable consumption does not appear to be sensitive to different levels of financial frictions. The effects on residential investment are more important, especially (sensitive) to the different specifications of the loan-to-value ratio."

Now, what is the story in Iacoviello and Neri? It is a very popular one: some households are constrained in terms of final consumption purchases by the fact that they cannot borrow against future income but only against the collateral value of their house. Accordingly, declines in housing prices—which would produce declines in housing investment in any model with a Q-theoretic mechanism—also can affect final consumption of other goods, thus bringing about sectoral co-movement. For example, Iacoviello and Neri (2010, p. 141) display a positive response of consumption to a housing preference shock in a baseline model, but a negative one in a variant without a collateral effect. In their benchmark setup, the income share of individuals that are borrowing constrained is about 20 percent.

Detailed microeconomic evidence produced by Hryshko, Luengo-Prado, and Sørenson (2010) shows that there are important departures from full consumption smoothing when individuals are hit by large negative income shocks and if they also live in areas that have been hit by important declines in real estate values. I interpret this evidence as indicating that credit constraints preclude the use of home equity and related loans to undertake consumption smoothing against adverse shocks. That is, there is some detailed microeconomic evidence for the mechanisms that Iacoviello and Neri (2010) (henceforth, IN) seek to integrate into the macro model.

But AR argue that the credit constraint mechanism does not seem to have a large effect on the operation of a macroeconomic model when it is implemented in the manner suggested by IN.[4] To make this argument, AR employ sensitivity analysis in figures 12 (response to a monetary policy shock) and 13 (response to a housing preference shock) across various values of the income share of constrained individuals and the level of the loan-to-value (LTV) ratio in the borrowing constraint. The differential effect shows up only in figure 13, which is the response to the housing preference shock that is also the main focus of IN. Standardizing the unit in the two studies, a 1 percent initial shock to housing prices produces a peak response of consumption of about .07 percent in IN, while it produces

[4]Sterk (2010) has also questioned how much such financial constraint mechanisms alter the sectoral co-movement within the financial frictions model of Monacelli (2009).

about a .06 percent response in AR. So, the two analyses seem to be telling a similar story about the magnitude of housing market spillovers, with IN stressing that the effect is positive and with AR stressing that it is positive and small from their perspective.[5]

Both studies indicate that labor market frictions—imperfect substitutability and nominal stickiness—are important for the dynamic response of the model to housing and monetary policy shocks.

5. Changing Monetary Policy

The purpose of constructing DSGE models is to provide answers to big questions like, "does it matter whether Spain is part of a currency union?" for which macroeconomists agree that the Lucas (1976) critique invalidates the use of reduced-form models like SVARs.

Aspachs-Bracons and Rabanal are interested in the specific big question: if Spain had been following an independent monetary policy, then would there have been important consequences of adopting a policy rule that included "leaning against house price inflation"?

Concretely, in figure 14, AR compare the response to a housing demand shock when monetary policy in their economy is alternatively (i) EMU monetary policy, which does not respond to developments in Spanish housing markets; (ii) an independent Spanish central bank following a strict inflation-targeting form of the Taylor rule; and (iii) an independent Spanish central bank leaning against house price inflation. They show that there is little difference between (i) and (ii). They highlight the finding that "leaning against housing inflation" policy does relatively little in terms of curtailing a housing price and investment boom, but does impose costs in terms of reduced output in the non-durable consumption goods sector, which did not arise under the alternative two policies.

[5]Overall, the "size" of the housing spillover is somewhat dependent on the context as well as these numerical values, as Matteo Iacoviello has stressed to me. There was a very large shock to the housing market in the United States and some other countries, so that multipliers which look small can nevertheless lead to a substantial response. Iacoviello points out that the .07 coefficient implies that a 20 percent decline in real housing values—roughly that in the United States—would lead to a 1.4 percent decline in aggregate consumption.

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Risky Mortgages in a DSGE Model*

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This paper develops a DSGE model with housing, risky mortgages, and endogenous default. Housing investment is subject to idiosyncratic risk, and some mortgages are defaulted in equilibrium. An unanticipated increase in the standard deviation of housing investment risk produces a credit crunch where delinquencies and mortgage interest rates increase, lending is curtailed, and aggregate demand for non-durable goods falls. The economy experiences a recession as a consequence of the credit crunch. The paper compares economies that differ only in the riskiness of housing investment. Economies with lower risk are characterized by lower steady-state mortgage default rates and higher loan-to-value and leverage ratios. The macroeconomic effects of an unanticipated increase in housing investment risk are amplified in high-leverage economies. Monetary policy plays an important role in the transmission of housing investment risk, as inertial interest rate rules generate deeper output contractions.

JEL Codes: E32, E44, G01, R31.

1. Introduction

The global financial crisis that began in August 2007 has its roots in increased mortgage delinquencies that put financial institutions into

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distress. The bursting of the housing bubble in the United States placed many borrowers in a difficult financial position, with mortgages they could not pay in the long run and larger than the value of the houses against which they were underwritten. As a result, the rate of seriously delinquent mortgages[1] increased from 2 percent in the third quarter of 2006 to 10 percent by the first quarter of 2010. Banks were forced to write down several hundred billion dollars in bad mortgages. These losses, combined with a high degree of opacity surrounding mortgage-backed securities and a complicated web of interconnected obligations among financial institutions, triggered a severe liquidity crisis in the interbank market. A credit crunch followed that caused failure of several financial institutions, brought many others close to it, raised interbank rates, and drastically reduced household access to borrowing. The fall in housing prices and tightened credit conditions forced many borrowers to quickly deleverage, cutting consumption and housing investment. The turmoil that started in the mortgage market spread to the rest of the economy to spark the Great Recession.

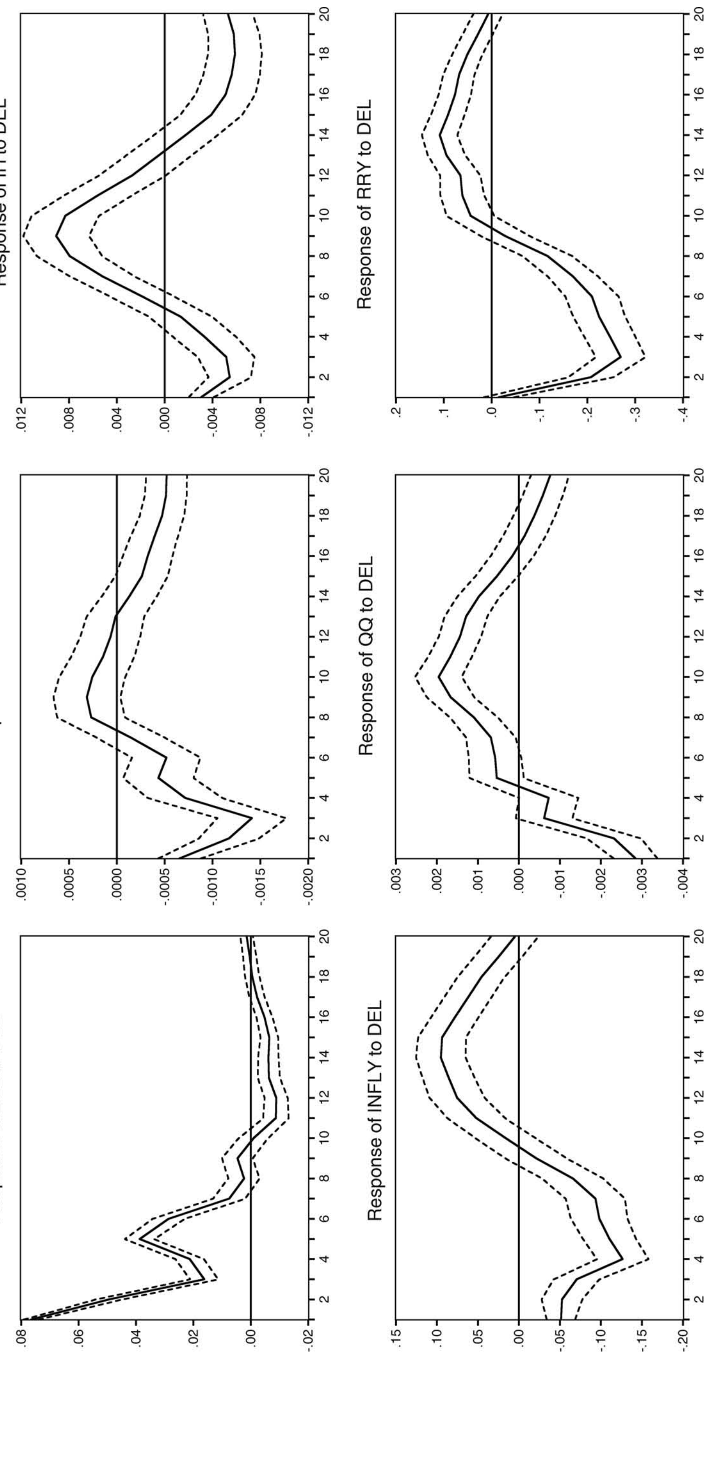
Several factors contributed to the depth and persistence of the recent recession. We focus on one of these factors: the increase in mortgage delinquencies and its transmission to the rest of the economy. Our goal is mainly methodological: we introduce endogenous default on mortgages in a dynamic stochastic general equilibrium (DSGE) model with housing. Endogenous default arises because housing investment is subject to idiosyncratic risk, which can bring loan repayment above the housing value. The paper analyzes how aggregate shocks affect the rate of default on mortgages and how an increase in the rate of default on mortgages transmits to the rest of the economy. Driven by recent events, we focus on an unanticipated increase in mortgage risk, which we model as an unanticipated increase in the volatility of idiosyncratic housing investment risk.

Figure 1 shows the impulse responses from a four-lag VAR with seriously delinquent mortgages (DEL), real per capita consumption (CC), real per capita residential investment (IH), the four-quarter change in the log of the implicit price deflator for the non-farm

[1]According to the National Delinquency Survey of the Mortgage Bankers Association, seriously delinquent mortgages are those more than ninety days past due or in foreclosure.

Figure 1. VAR Evidence

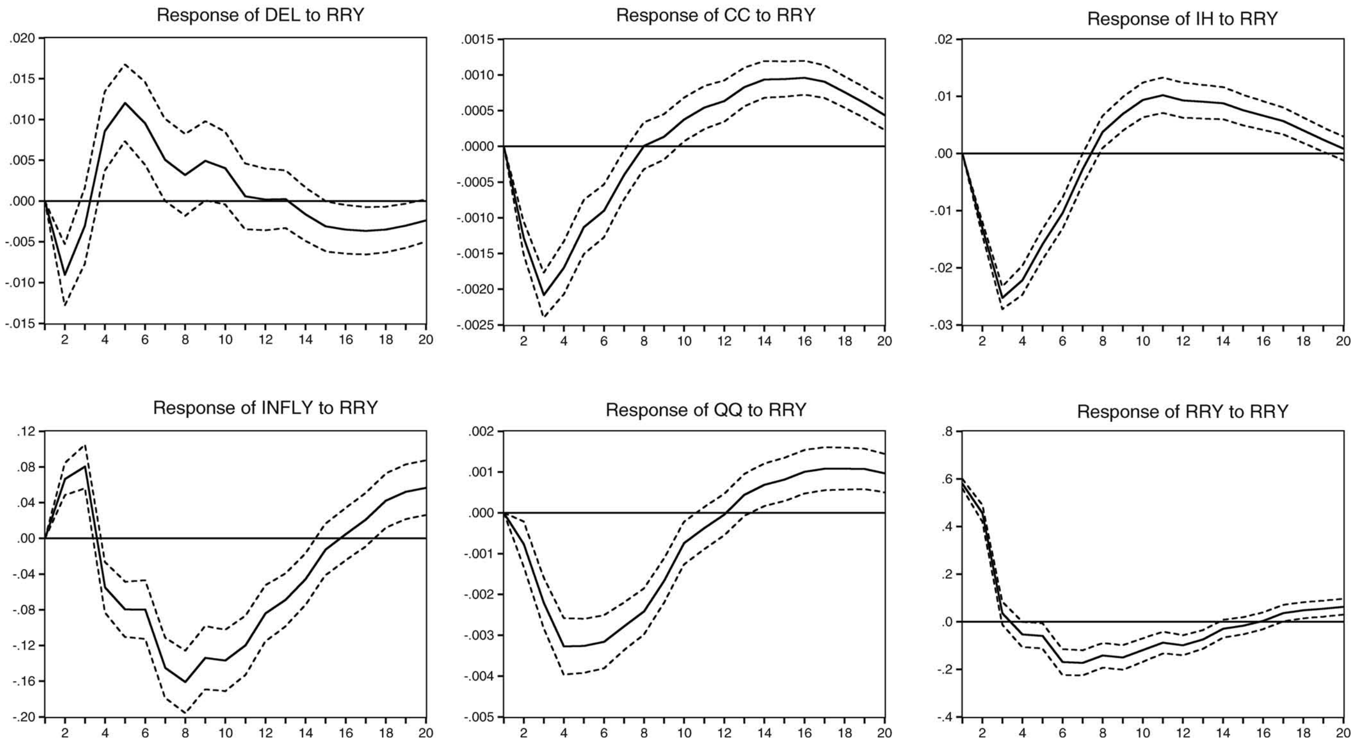
A. Impulse Responses to Cholesky One-Standard-Deviation Innovation to Delinquencies



(continued)

Figure 1. (Continued)

B. Impulse Responses to Cholesky One-Standard-Deviation Innovation to the Nominal Interest Rate



Notes: VAR estimated from 1980:Q1 to 2006:Q4. The dashed lines indicate the +/− one-standard-error bands. The Cholesky ordering is DEL, CC, IH, INFLY, QQ, and RRY. The vertical axis shows the percent deviation from baseline.

business sector (INFLY), real house prices (QQ), and the nominal short-term interest rate (RRY) from 1980:Q1 to 2006:Q4.[2] All data are for the United States. The starting date for our VAR is dictated by data availability on mortgage delinquencies. On the other hand, we purposely limit our sample to 2006:Q4 to exclude the bursting of the U.S. housing bubble and the sharp increase in delinquencies experienced since the first quarter of 2007. Variables are listed in their Cholesky ordering. Delinquencies are ordered first because we allow for a shock in the mortgage market and mortgage delinquencies to affect contemporaneously all other variables. Ordering delinquencies after the other variables, and in particular after housing prices, does not change the qualitative responses to an innovation to delinquencies, although standard errors become larger. As is standard in the literature, we order the nominal short-term interest rate last. All variables are detrended using the Hodrick-Prescott filter.

Panel A of figure 1 illustrates the impulse responses of our six variables to a one-standard-deviation innovation in serious delinquencies. It suggests a significant short-run negative response of private consumption, residential investment, inflation, real house prices, and the nominal interest rate to a positive innovation to mortgage delinquencies. Residential investment and house prices, the variables connected to the housing sector, fall on impact and rebound after five quarters. The variables connected to the non-durable sector, on the other hand, experience a more persistent decline, as private consumption and inflation of non-durable goods remain below baseline for eight quarters. This evidence points to a significant transmission mechanism of shocks from the mortgage market to the rest of the economy.

Panel B of figure 1 shows the impulse responses of our six variables to a one-standard-deviation innovation in the nominal interest rate. An increase in the nominal interest rate reduces consumption and residential investment. As already pointed out in the literature,[3] the output response in the durable sector—in our case, residential investment—is stronger than in the non-durable sector. Real house prices fall following an innovation to the nominal interest rate, as is

[2]See appendix 1 for data definition and sources.
[3]See Erceg and Levin (2006).

consistent with the evidence in Iacoviello (2005). Mortgage delinquencies fall on impact but increase soon afterward and remain above baseline for about six quarters. Mortgage delinquencies fall in response to an innovation in residential investment (not shown in the paper but available in appendix 3[4]). Hence, mortgage delinquencies react significantly to aggregate shocks. To sum up, the VAR evidence points to the fact that mortgage delinquencies are an endogenous variable that affects and is affected by other fundamental macroeconomic variables. Our goal is to build a general equilibrium macroeconomic model that captures these relationships.

Our model features two households that differ in terms of their discount factor. Savers have a higher discount factor than Borrowers and, in equilibrium, lend to Borrowers. Preferences are specified over consumption of non-durable goods, housing services, and hours worked. Borrowers use their houses as collateral for mortgages and experience idiosyncratic housing investment shocks that are private information. Lenders (Savers) must pay a monitoring cost to observe Borrowers' realized housing return. Borrowers experiencing low realizations of the idiosyncratic shock default on their mortgages; Borrowers who repay their mortgages pay a state-contingent adjustable mortgage rate that is above the risk-free one. Hence, our model is characterized by endogenous default on mortgages and a mortgage, or external finance, premium.

We study the dynamic response to an unanticipated increase in the standard deviation of idiosyncratic risk to housing investment, which we also refer to as mortgage risk. More precisely, we assume that the standard deviation of mortgage risk follows an exogenous stochastic process and we analyze the dynamic response of our model following a positive shock to such standard deviation. This assumption captures the idea that housing investment risk is time variant. For example, the entrance in the mortgage market of subprime debtors may have increased mortgage risk, and our model can capture this increase in riskiness as an exogenous time variation in risk. Our model produces a credit crunch that generates a recession not only in the housing sector but also in the non-durable one. Mortgage

[4]Appendix 3 is available on the corresponding author's web site at http://cfi.epfl.ch/cms/page-40442.html.

default rates as well as the mortgage premium, namely the spread between the adjustable mortgage rate and the risk-free rate, increase. Households with mortgages are particularly hurt. Borrowers experience a deterioration of their financial situation and tighter credit conditions, which force them to deleverage and cut non-durable consumption and housing investment. Aggregate non-durable consumption and total output fall. The relative price of houses falls and then rapidly rebounds. An increase in mortgage risk generates a recession, but it fails to generate a large and persistent decline in real housing prices.

We consider two economies that differ only in mortgage risk. The economy with a lower steady-state standard deviation of mortgage risk has a lower steady-state rate of default on mortgages. As a result, mortgages are larger and the economy is more leveraged. Economies with higher leverage ratios display more redistribution and more polarized responses to aggregate shocks, as the two households stand at the opposite sides of the mortgage contract. When mortgage risk increases, Borrowers are hurt more and the effects of the credit crunch are amplified. Hence, more leveraged economies suffer deeper recessions.

We analyze the dynamic response to an increase in mortgage risk under alternative specifications of the interest rate rule that governs monetary policy. More inertial rules feature less aggressive interest rate reductions in response to a mortgage risk shock that ultimately lead to deeper output contractions in the non-durable sector and in the economy. Non-inertial interest rate rules, on the other hand, generate large negative interest rate responses that boost Savers' non-durable consumption and successfully smooth out the contraction in the non-durable sector. Hence, interest rate flexibility is important in responding to a mortgage risk shock.

The rest of the paper is organized as follows. Section 2 discusses the related literature and section 3 presents the model. Section 4 presents two calibrations, benchmark and low leverage, and analyzes the difference in the steady state of the two economies. Section 5 analyzes the transmission mechanism in response to a mortgage risk shock in the benchmark and low-leverage economy, and it analyzes the role of interest rate flexibility. Section 6 analyzes the dynamic response of the model to a monetary shock. Section 7 summarizes and suggests future directions for research.

2. Related Literature

A growing literature embeds durable goods in DSGE models. Barsky, House, and Kimball (2007) introduce durable goods in an otherwise standard sticky-price model and show that the pricing of durable goods plays a key role in the response to a monetary shock. More precisely, if prices of durable goods are sticky, the model behaves as if most prices are sticky. On the other hand, if prices of durable goods are flexible, the model behaves as if most prices are flexible. When durable prices are flexible, the durable goods sector shrinks in response to a monetary expansion, thereby offsetting the expansion in the non-durable goods sector and leaving GDP unchanged. Erceg and Levin (2006) use VAR evidence to document positive sectoral co-movement as well as higher sensitivity of the durable goods sector (relative to the non-durable one) to the nominal interest rate in response to a monetary shock. To match this empirical evidence with the model impulse responses, Erceg and Levin (2006) assume wage stickiness and the same degree of price stickiness in the durable and non-durable sector. They show that social welfare depends on the variances of sectoral output gaps and on the dispersion of prices and wages in each sector. Hence, optimal monetary policy is well approximated by a simple rule that targets a weighted average of wage and price inflation. Carlstrom and Fuerst (2006) underline the existence of a co-movement puzzle following a monetary policy shock since negative sectoral co-movement and price stickiness in the durable sector are both counterfactual. They suggest introducing sticky wages and adjustment costs in the durable sector to bring the model predictions closer to the empirical findings.

A second group of contributions incorporates financial frictions à la Kiyotaki and Moore (1997) into a model with housing as a durable good, sticky prices, and two households with different discount factors. To ensure the existence of an equilibrium, Iacoviello (2005) assumes an exogenous borrowing constraint according to which impatient agents can borrow a fraction of the expected discounted future value of their houses. Using housing as collateral generates a financial accelerator in response to demand shocks that helps reconcile the VAR evidence with the impulse responses of the model. Iacoviello and Neri (2010) extend the work of Iacoviello (2005) and write a DSGE model with housing that is estimated using U.S. data for the period 1965:Q1 to 2006:Q3. Calza, Monacelli, and Stracca (2009) analyze how the transmission mechanism of monetary shocks in a housing model à la Iacoviello is affected by alternative values of the downpayment rate and the interest rate mortgage structure. Monacelli (2009) shows that a model where housing is used as collateral features co-movement in response to a monetary shock, provided the durable sector displays some degree of price stickiness.

Our housing model draws a number of features from these contributions. As in Iacoviello (2005) and Iacoviello and Neri (2010), we build a model with two household groups and housing as a durable good. In our model, however, some loans are not repaid. In fact, the novelty of our paper is to introduce idiosyncratic risk in housing investment and the possibility for loans to be defaulted on, which results in an endogenous borrowing constraint similar to that for entrepreneurs in Bernanke, Gertler, and Gilchrist (1999).

The literature on the financial accelerator is vast. Starting with Carlstrom and Fuerst (1997) and Bernanke, Gertler, and Gilchrist (1999), many papers have introduced this credit friction in DSGE models to analyze its role on the transmission of shocks. We do not present an exhaustive review of the financial accelerator literature here, but rather focus on some recent applications that are closer to our study. Aoki, Proudman, and Vlieghe (2004) model risk-neutral homeowners that buy houses and rent them to a representative household. The homeowners' problem is akin to that of entrepreneurs in Bernanke, Gertler, and Gilchrist (1999). Households are either consumption smoothers or rule-of-thumb consumers who consume their labor income and transfers from homeowners. Aoki, Proudman, and Vlieghe (2004) analyze the effects of monetary policy shocks when transactions costs for borrowing against housing equity fall. In our model, mortgage default and the associated loss of housing stock affect risk-averse, borrowing-constrained consumers rather than risk-neutral homeowners, so that the transmission mechanism is different. Moreover, our focus is on an unanticipated increase in idiosyncratic mortgage risk and its effects on the macroeconomy.

Christiano, Motto, and Rostagno (2009) augment a standard monetary DSGE model to include financial markets and a financial accelerator and fit the model to European and U.S. data. They analyze an increase in the standard deviation of idiosyncratic risk in loans to entrepreneurs. In our setting, idiosyncratic risk is in mortgage loans. Cohen-Cole and Martinez-Garcia (2008) consider a model with a financial accelerator as in Bernanke, Gertler, and Gilchrist (1999) and introduce systemic risk, namely an aggregate variable that affects the variance of idiosyncratic risk, and banking regulation. Similarly, Faia and Monacelli (2007) consider systemic risk as a correlation between the mean of the idiosyncratic risk and the aggregate shock. We do not consider systemic risk but allow for time variation in the standard deviation of the distribution of idiosyncratic housing investment risk.

Some recent papers examine the effects of different shocks to loan repayment. Dellas, Diba, and Loisel (2010) add a banking sector to an otherwise standard New Keynesian model and consider some financial shocks, among them an increase in the exogenous rate of default of firms on bank loans. They argue that price stability is all that matters for monetary policy, even when financial factors are present. Our work differs from Dellas, Diba, and Loisel (2010) in a number of ways. Our model features a housing sector but no financial sector; moreover, default on loans is endogenous in our model while it is exogenous in Dellas, Diba, and Loisel (2010). Iacoviello (2010) introduces the banking sector in a model with housing and studies an exogenous shock to how much borrowers repay. This repayment shock is exogenous and different from default because borrowers do not lose their houses following a negative repayment shock.

3. The Model

Our starting point is a model with patient and impatient households that consume non-durable goods and housing services and work. Many features of our model draw from the housing model of Iacoviello (2005), Monacelli (2009), and Iacoviello and Neri (2010). Our focus, however, is on the mortgage contract and on how its features matter for the transmission of shocks. We do not rely on an exogenous borrowing constraint, but rather derive it endogenously from the lenders' participation constraint after explicitly introducing idiosyncratic risk and default.

3.1 Households

The economy is populated by a continuum of households distributed over the $[0, 1]$ interval. A fraction ψ of identical households has discount factor β while the remaining fraction $1 - \psi$ has discount factor $\gamma > \beta$. We are going to refer to the households with the lower discount factor as Borrowers, as these households value current consumption relatively more than the other agents and therefore want to borrow. We are going to refer to households with the higher discount factor as Savers.

3.1.1 Borrowers

Borrowers have a lifetime utility function given by

$$\sum_{t=0}^{\infty} \beta^t E_0\{U(X_t, N_{C,t}, N_{H,t})\}, \quad 0 < \beta < 1, \tag{1}$$

where $N_{C,t}$ is hours worked in the non-durable sector, $N_{H,t}$ is hours worked in the housing sector, and X_t is an index of non-durable and durable consumption services defined as

$$X_t \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_t^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} H_{t+1}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where C_t denotes consumption of non-durable goods, H_{t+1} denotes consumption of housing services, α is the share of housing in the consumption index, and $\eta \geq 0$ is the elasticity of substitution between housing and non-durable services. We assume that housing services in period t are equal to the housing stock chosen at the beginning of period t, H_{t+1}. Assuming that services are a fraction of the stock is not going to change qualitatively our results.

We assume the following period utility function:

$$U(X_t, N_t) \equiv \ln X_t - \frac{\nu}{1+\varphi}\left[N_{C,t}^{1+\xi} + N_{H,t}^{1+\xi}\right]^{\frac{1+\varphi}{1+\xi}}, \quad \varphi, \xi \geq 0. \tag{3}$$

Our specification for the disutility of labor follows Iacoviello and Neri (2010) in allowing that hours in the non-durable and housing sector are imperfect substitutes, as is consistent with the evidence found by Horvath (2000). For $\xi = 0$, hours in the non-durable and housing sector are perfect substitutes. On the other hand, positive values of ξ result in wages not being equalized in the two sectors and the substitution of hours across sectors in response to wage differentials being reduced. The parameter φ is the inverse of the Frisch labor supply elasticity.

Borrowers are subject to the sequence of budget constraints:

$$P_{C,t}C_t + P_{H,t}H_{t+1} + [1 - F_t(\bar{\omega}_t)](1 + R_{Z,t})L_t \\ = L_{t+1} + W_{C,t}N_{C,t} + W_{H,t}N_{H,t} + (1 - \delta)[1 - G_t(\bar{\omega}_t)]P_{H,t}H_t, \tag{4}$$

where $P_{C,t}$ is the price of non-durable goods, $P_{H,t}$ is the price of housing, and L_{t+1} are the loans taken from Savers at t to be repaid in period $t + 1$. $R_{Z,t}$ is the state-contingent interest rate that non-defaulting Borrowers pay at t on the loans L_t taken at time $t - 1$, and $W_{j,t}$ is the nominal wage in sector $j = C, H$. In equilibrium, some loans are going to be defaulted on. The term $G_t(\bar{\omega}_t)$ represents the fraction of Borrowers' housing stock that has been seized by Savers as a consequence of default in period t; $[1 - F_t(\bar{\omega}_t)]$ is the fraction of loans that is repaid to lenders. We explicitly derive and explain these two terms later. The housing stock depreciates at the rate δ. Each household decides non-durable good consumption, housing investment (and consumption), working hours in the two sectors, and loans.

It is worth noticing at this point that the state-contingent interest rate $R_{Z,t}$ is determined at time t after the realization of shocks and in order to satisfy the participation constraint of lenders, which we explain in detail later. Hence, our mortgage contract is characterized by adjustable interest rates.

Each household consists of many members. The household decides total housing investment H_{t+1} and the state-contingent mortgage rates to be paid next period on the contracts signed this period. The household then assigns equal resources to each i-th member to purchase the housing stock H^i_{t+1}, where $\int_i H^i_{t+1} di = H_{t+1}$. The i-th member finalizes the mortgage contract connected to the housing stock H^i_{t+1} following the instructions of the household and manages his housing stock. All members are ex ante identical. After the mortgage contract is finalized, the i-th household member experiences an idiosyncratic shock ω^i_{t+1} such that his ex post housing value is $\omega^i_{t+1} P_{H,t+1} H^i_{t+1}$. This assumption captures the idea that housing investment is risky. An alternative interpretation is that housing prices are subject to idiosyncratic risk so that the ex post price of the housing stock i is equal to $\omega^i_{t+1} P_{H,t+1}$. This price risk could capture the fact that housing prices display geographical variation. The random variable ω^i_{t+1} is i.i.d. across members of the same household and log-normally distributed with a cumulative distribution function $F_{t+1}(\omega^i_{t+1})$, which obeys standard regularity conditions.[5] The mean and variance of $\ln \omega^i_{t+1}$ are chosen so that $E_t(\omega^i_{t+1}) = 1$ at all times. This implies that while there is idiosyncratic risk at the household-member level, there is no risk at the household level and $E_t(\omega^i_{t+1} H^i_{t+1}) = H_{t+1}$. We are going to assume that housing investment riskiness can change over time, namely that the standard deviation $\sigma_{\omega,t}$ of $\ln \omega^i_t$ is subject to an exogenous shock and displays time variation. The random variable ω^i_{t+1} is observed by the i-th member and the household but can only be observed by lenders after paying a monitoring cost.

After idiosyncratic shocks are realized, the household member decides whether to repay the mortgage or to default. Loans connected to housing stocks that experienced high realizations of the idiosyncratic shock ω^i_{t+1} are repaid, while loans connected to housing stocks with low realizations are defaulted on. Let $\bar{\omega}_{t+1}$ be the threshold value of the idiosyncratic shock for which the member is willing to repay the loan at the contractual rate $R_{Z,t+1}$, namely

$$\bar{\omega}_{t+1}(1-\delta) P_{H,t+1} H_{t+1} = (1 + R_{Z,t+1}) L_{t+1}. \tag{5}$$

Loans connected to $\omega^i_{t+1} \in [\bar{\omega}_{t+1}, \infty]$ are repaid and Borrowers pay $(1 + R_{Z,t+1}) L_{t+1}$. On the other hand, loans connected to $\omega^i_{t+1} \in [0, \bar{\omega}_{t+1})$ are defaulted on. Lenders pay a monitoring cost to assess and seize the collateral connected to the defaulted loan. It is the presence of monitoring that induces Borrowers to truthfully

[5]The c.d.f. is continuous, at least once-differentiable, and it satisfies

$$\frac{\partial \omega h(\omega)}{\partial \omega} > 0,$$

where $h(\omega)$ is the hazard rate.

reveal their idiosyncratic shock and justifies the incentive compatibility constraint (5).[6] The household members that default on their mortgages lose their housing stocks.

Mortgages are non-recourse in our model—that is to say, mortgages are secured by the pledge of collateral (the house), and the lender's recovery is strictly limited to the collateral. Defaulting Borrowers are not personally liable for the difference between the loan and the collateral value. Some comments are in order. This is a natural assumption in our model because housing is the only asset held by Borrowers. In addition to this, non-recourse debt is broadly applicable to most U.S. states, especially those that experienced soaring mortgage delinquencies, and the focus of our paper is on the United States. At last, non-recourse debt captures the reality of subprime mortgages, which were at the heart of the recent financial crisis.

In Bernanke, Gertler, and Gilchrist (1999) the monitoring cost is equal to a fraction of the realized gross payoff to the defaulting firm's capital. We follow Bernanke, Gertler, and Gilchrist (1999) and assume that the monitoring cost in our model is equal to the fraction μ of the housing value, $\mu\omega_{t+1}^{i} P_{H,t} H_{t+1}$. This assumption has two important implications. The first implication is that the foreclosure cost is proportional to the value of the house under foreclosure. The second implication is that mortgage default causes a decline in the housing stock and services. The second implication plays an important role in our results. We discuss its relevance as well as an alternative assumption regarding monitoring costs in the concluding section.

Regarding the defaulting household members, we follow the literature on matching and assume there is perfect insurance among household members so that consumption of non-durable goods and housing services are ex post equal across all members of the Borrower household. Hence, Borrower household members are ex post identical.

Following Bernanke, Gertler, and Gilchrist (1999), we consider a one-period mortgage contract that guarantees lenders a predetermined rate of return on their total loans. At time t Savers make total loans L_{t+1} to Borrowers and demand the gross rate of return

[6] See the seminal work of Townsend (1979).

$1 + R_{L,t}$. This rate of return is predetermined at t and non-state contingent. Hence, the time t participation constraint of lenders is given by

$$(1 + R_{L,t})L_{t+1} = \int_0^{\bar{\omega}_{t+1}} \omega_{t+1}(1-\mu)(1-\delta)P_{H,t+1}H_{t+1}f_{t+1}(\omega)d\omega + \int_{\bar{\omega}_{t+1}}^{\infty} (1 + R_{Z,t+1})L_{t+1}f_{t+1}(\omega)d\omega, \tag{6}$$

where $f_t(\omega)$ is the probability density function of ω, which is time variant because it is subject to an exogenous shock to its standard deviation. The return on total loans is equal to the housing stock net of monitoring costs and depreciation of defaulting Borrower members (the first term on the right-hand side of (6)) and the repayment by non-defaulting members (the second term on the right-hand side of (6)). After idiosyncratic and aggregate shocks have realized, the threshold value $\bar{\omega}_{t+1}$ and the state-contingent mortgage rate $R_{Z,t+1}$ are determined so as to satisfy the participation constraint above. Notice that the participation constraint holds state by state and not in expected terms. In other words, an aggregate state that raises $\bar{\omega}_{t+1}$ and the rate of default on mortgages generates an increase in the adjustable rate $R_{Z,t+1}$ paid by non-defaulting members in order to satisfy the participation constraint (6) in that state. This implies that periods characterized by high mortgage default rates are also accompanied by high mortgage interest rates in our model.

We use one-period debt contracts as in Bernanke, Gertler, and Gilchrist (1999) for tractability reasons. In reality, conventional U.S. mortgages typically have a fixed thirty-year term and about 70 percent of mortgages have fixed rates, even though this percentage has changed in recent years. Moreover, subprime mortgages with nontraditional ARM features were at the heart of the recent crisis. Our model does not consider these alternative mortgage instruments and therefore cannot capture their role at the onset of the crisis. Nevertheless, our general equilibrium model captures the effect of a fall in housing prices on mortgage default rates and its transmission to the rest of the economy.

We simplify the Borrower problem as follows. Let

$$G_{t+1}(\bar{\omega}_{t+1}) \equiv \int_0^{\bar{\omega}_{t+1}} \omega_{t+1}f_{t+1}(\omega)d\omega \tag{7}$$

be the expected value of the idiosyncratic shock conditional on the shock being less than or equal to the threshold value $\bar{\omega}_{t+1}$, multiplied by the probability of default, and let

$$\Gamma_{t+1}(\bar{\omega}_{t+1}) \equiv \bar{\omega}_{t+1} \int_{\bar{\omega}_{t+1}}^{\infty} f_{t+1}(\omega) d\omega + G_{t+1}(\bar{\omega}_{t+1}) \tag{8}$$

be the expected share of housing value, gross of monitoring costs, that goes to lenders. Then the participation constraint can be written more compactly as

$$(1+R_{L,t}) l_{t+1} = [\Gamma_{t+1}(\bar{\omega}_{t+1}) - \mu G_{t+1}(\bar{\omega}_{t+1})](1-\delta) p_{H,t+1} \pi_{C,t+1} H_{t+1}, \tag{9}$$

where $p_{H,t+1}$ is the relative price of houses in terms of non-durable consumption and l_{t+1} are real loans, namely $L_{t+1}/P_{C,t}$. The loan-to-value ratio is

$$\Gamma_{t+1}(\bar{\omega}_{t+1}) - \mu G_{t+1}(\bar{\omega}_{t+1}) \tag{10}$$

and it measures the size of the loan (principal plus interests) as a fraction of the net housing value. The loan-to-value ratio also measures the net share of the housing value that goes to the lender for repayment.

Following the decision to default at time $t+1$, Borrowers are left with the following stock of housing:

$$\begin{aligned} &\int_{\bar{\omega}_{t+1}}^{\infty} \omega_{t+1}(1-\delta) P_{H,t} H_{t+1} f_{t+1}(\omega) d\omega \\ &\qquad = [1 - G_{t+1}(\bar{\omega}_{t+1})](1-\delta) P_{H,t} H_{t+1}, \end{aligned} \tag{11}$$

where the second equality makes use of the fact that $E_t(\omega_{t+1}) = 1$. This is the expression used in the Borrowers budget constraint (4).

Using the relationship between $\bar{\omega}_{t+1}$ and $R_{Z,t+1}$ in (5) we can eliminate $R_{Z,t}$ from the Borrowers budget constraint and rewrite it in real terms as

$$\begin{aligned} &C_t + p_{H,t} H_{t+1} + (1 + R_{L,t-1}) \frac{l_t}{\pi_{C,t}} \\ &= l_{t+1} + (1-\delta)[1 - \mu G_t(\bar{\omega}_t)] p_{H,t} H_t + w_{C,t} N_{C,t} + w_{H,t} N_{H,t}, \end{aligned} \tag{12}$$

where $\pi_{C,t}$ is non-durable-good inflation and $w_{C,t}, w_{H,t}$ are real wages in the C and H sector, respectively, in terms of $P_{C,t}$. Borrowers maximize (1) subject to the budget constraint (12) and the participation constraint (9) with respect to the variables $C_t, H_{t+1}, N_{C,t}, N_{H,t}, l_{t+1}, \bar{\omega}_{t+1}$. The respective first-order conditions are

$$U_{C,t} - \lambda_{BC,t} = 0, \tag{13}$$

$$\begin{aligned} U_{H,t+1} - \lambda_{BC,t} p_{H,t} + \beta(1-\delta) E_t\{[1 - \mu G_{t+1}(\bar{\omega}_{t+1})] p_{H,t+1} \lambda_{BC,t+1} \\ + \lambda_{PC,t+1} p_{H,t+1} \pi_{C,t+1} [\Gamma_{t+1}(\bar{\omega}_{t+1}) - \mu G_{t+1}(\bar{\omega}_{t+1})]\} = 0, \end{aligned} \tag{14}$$

$$U_{N_j,t} + \lambda_{BC,t} w_{j,t} = 0, \quad j \in \{C, H\}, \tag{15}$$

$$\lambda_{BC,t} - (1 + R_{L,t}) E_t \left[\lambda_{PC,t+1} + \beta \frac{\lambda_{BC,t+1}}{\pi_{C,t+1}} \right] = 0, \tag{16}$$

$$\begin{aligned} -\beta \lambda_{BC,t+1} \mu G'_{t+1}(\bar{\omega}_{t+1}) + \lambda_{PC,t+1} \pi_{C,t+1} \left[\Gamma'_{t+1}(\bar{\omega}_{t+1}) \right. \\ \left. - \mu G'_{t+1}(\bar{\omega}_{t+1}) \right] = 0, \end{aligned} \tag{17}$$

where $\lambda_{BC,t}$ is the Lagrangian multiplier on Borrowers budget constraint (12) and $\lambda_{PC,t+1}$ is the Lagrangian multiplier on the participation constraint (9). Notice that the first-order condition with respect to $\bar{\omega}_{t+1}$ is state by state and not in expected terms.

3.1.2 Savers

We denote Savers' variables with a ˜. Savers maximize lifetime utility

$$\max \sum_{t=0}^{\infty} \gamma^t E_0\{U(\widetilde{X}_t, \widetilde{N}_{C,t}, \widetilde{N}_{H,t})\}, \quad 0 < \beta < \gamma < 1, \tag{18}$$

where $\widetilde{X}_t$ is defined similarly to (2). We assume the same utility function for Savers as for Borrowers. Savers maximize lifetime utility subject to the sequence of budget constraints:

$$\begin{aligned} \widetilde{C}_t + p_{H,t} \widetilde{H}_{t+1} + \widetilde{l}_{t+1} = (1-\delta) p_{H,t} \widetilde{H}_t + (1 + R_{L,t-1}) \frac{\widetilde{l}_t}{\pi_{C,t}} \\ + \widetilde{w}_{C,t} \widetilde{N}_{C,t} + \widetilde{w}_{H,t} \widetilde{N}_{H,t} + \widetilde{\Delta}_t, \end{aligned} \tag{19}$$

where $\widetilde{\Delta}_t$ are profits in the intermediate goods sector, which are taken as given.

Savers maximize (18) subject to the budget constraint (19) with respect to $\widetilde{C}_t, \widetilde{H}_{t+1}, \widetilde{N}_{C,t}, \widetilde{N}_{H,t}$, and $\widetilde{l}_{t+1}$. The first-order conditions, respectively, are

$$U_{\widetilde{C},t} - \widetilde{\lambda}_{BC,t} = 0, \tag{20}$$

$$U_{\widetilde{H},t+1} - \widetilde{\lambda}_{BC,t} p_{H,t} + \gamma(1-\delta) E_t[\widetilde{\lambda}_{BC,t+1} p_{H,t+1}] = 0, \tag{21}$$

$$U_{\widetilde{N}_j,t} + \widetilde{\lambda}_{BC,t} \widetilde{w}_{j,t} = 0, \quad j \in \{C, H\}, \tag{22}$$

$$-\widetilde{\lambda}_{BC,t} + \gamma(1 + R_{L,t}) E_t \left[\frac{\widetilde{\lambda}_{BC,t+1}}{\pi_{C,t+1}} \right] = 0, \tag{23}$$

where $\widetilde{\lambda}_{BC,t}$ is the Lagrangian multiplier on Savers budget constraint (19).

3.2 Firms and Technology

Both the non-durable C and the housing H sector have intermediate and final goods producers.

3.2.1 Final Goods Producers

Final goods producers are perfectly competitive and produce $Y_{j,t}$, $j = C, H$. The technology in the j-th final goods sector is given by

$$Y_{j,t} = \left(\int_0^1 Y_{j,t}(i)^{\frac{\varepsilon_j - 1}{\varepsilon_j}} di \right)^{\frac{\varepsilon_j}{\varepsilon_j - 1}}, \tag{24}$$

where $\varepsilon_j > 1$ is the elasticity of substitution among intermediate goods in sector j. Standard profit maximization implies that the demand for intermediate good i is given by

$$Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}} \right)^{-\varepsilon_j} Y_{j,t}, \ \forall i, \tag{25}$$

where the price index is

$$P_{j,t} = \left(\int_0^1 P_{j,t}(i)^{1-\varepsilon_j} di \right)^{\frac{1}{1-\varepsilon_j}}.$$

3.2.2 Intermediate Goods Sectors

There are two intermediate goods sectors $j \in \{C, H\}$, and in each intermediate sector there is a continuum of firms, each producing a differentiated good $i \in [0, 1]$. These firms are monopolistically competitive. We assume that intermediate goods firms readjust their price according to a Calvo-type mechanism. Hence, in any given period, a firm in sector j may reset its price with probability $1 - \theta_j$.

Intermediate goods firm i produces according to the following production function:

$$Y_{j,t}(i) = A_{j,t}\left[\zeta^{\frac{1}{\varsigma}} N_{j,t}(i)^{\frac{\varsigma-1}{\varsigma}} + (1-\zeta)^{\frac{1}{\varsigma}} \widetilde{N}_{j,t}(i)^{\frac{\varsigma-1}{\varsigma}}\right]^{\frac{\varsigma}{\varsigma-1}}, \quad j \in \{C, H\}, \tag{26}$$

where $A_{j,t}$ is the stochastic level of technology in sector j and $N_{j,t}(i)$ and $\widetilde{N}_{j,t}(i)$ are the two labor types supplied, respectively, by Borrowers and Savers. $\zeta \in (0, 1)$ is the labor share of Borrowers in the production function and $\varsigma > 0$ is the elasticity of substitution across labor inputs. When ς goes to infinity, labor inputs become perfect substitutes. For simplicity these two parameters are assumed to be equal across sectors.

A firm i reoptimizing in period t chooses labor and its nominal price $P^*_{j,t}(i)$ so as to maximize the expected discount sum of nominal profits over the period during which its price remains unchanged. Thus, the maximization problem for firm i is given by

$$\begin{aligned} \max_{P^*_{j,t}(i), N_{j,t+k|t}(i), \widetilde{N}_{j,t+k|t}(i)} & E_t \Bigg\{ \sum_{k=0}^{\infty} \theta_j^k \Lambda_{t,t+k}\big[P^*_{j,t}(i) Y_{j,t+k|t}(i) \\ & - W_{j,t+k} N_{j,t+k|t}(i) - \widetilde{W}_{j,t+k} \widetilde{N}_{j,t+k|t}(i) \\ & + mc_{j,t+k|t}(i) P_{j,t+k}\big[A_{j,t+k}\big[\zeta^{\frac{1}{\varsigma}} N_{j,t+k|t}(i)^{\frac{\varsigma-1}{\varsigma}} \\ & + (1-\zeta)^{\frac{1}{\varsigma}} \widetilde{N}_{j,t+k|t}(i)^{\frac{\varsigma-1}{\varsigma}}\big]^{\frac{\varsigma}{\varsigma-1}} - Y_{j,t+k|t}(i)\big]\big] \Bigg\}, \end{aligned} \tag{27}$$

where $Y_{j,t+k|t}(i)$ denotes output in period $t + k$ for a firm i that last changed its price in period t. A similar interpretation applies to $N_{j,t+k|t}(i)$ and $\widetilde{N}_{j,t+k|t}(i)$. $mc_{j,t+k|t}(i)$ is the real marginal cost of a firm i that last changed its price in period t.

In (27) the demand and the stochastic discount factor are, respectively, given by

$$Y_{j,t+k|t}(i) = \left(\frac{P^*_{j,t}(i)}{P_{j,t+k}}\right)^{-\varepsilon_j} Y_{j,t+k}, \quad \Lambda_{t,t+k} \equiv \frac{\gamma^k \widetilde{\lambda}_{BC,t+k}}{\widetilde{\lambda}_{BC,t}}.$$

The first-order conditions relative to $N_{j,t+k|t}(i)$ and $\widetilde{N}_{j,t+k|t}(i)$ are

$$-W_{j,t+k} + mc_{j,t+k|t}(i) P_{j,t+k} Y_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} \zeta^{\frac{1}{\varsigma}} N_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} = 0, \tag{28}$$

$$-\widetilde{W}_{j,t+k} + mc_{j,t+k|t}(i) P_{j,t+k} Y_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} (1-\zeta)^{\frac{1}{\varsigma}} \widetilde{N}_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} = 0, \tag{29}$$

which state that the nominal marginal cost equals the ratio of the nominal wage to the marginal product of each type of labor input. By rearranging (28) and (29), we obtain

$$mc_{j,t+k|t}(i) = \frac{1}{A_{j,t+k} P_{j,t+k}} \left[\zeta W^{1-\varsigma}_{j,t+k} + (1-\zeta) \widetilde{W}^{1-\varsigma}_{j,t+k}\right]^{\frac{1}{1-\varsigma}}. \tag{30}$$

According to (30), $mc_{j,t+k|t}(i) = mc_{j,t+k}$. Marginal costs are equal across firms because wages are the same across all firms.

The first-order condition relative to the price is given by

$$E_t \left\{ \sum_{k=0}^{\infty} \theta_j^k \Lambda_{t,t+k} \left[\left(\frac{P^*_{j,t}(i)}{P_{j,t+k}}\right)^{(-\varepsilon_j - 1)} \times Y_{j,t+k} \left(\frac{P^*_{j,t}(i)}{P_{j,t+k}} - \frac{\varepsilon_j}{\varepsilon_j - 1} mc_{t+k} \right) \right] \right\} = 0. \tag{31}$$

Finally, it can be shown[7] that, under Calvo price setting, the optimal price set by reoptimizing firms is linked to the aggregate price behavior by the following condition:

$$\left(\frac{P^*_{j,t}}{P_{j,t}}\right)^{(1-\varepsilon_j)} = \frac{1 - \theta_j \pi_{j,t}^{\varepsilon_j - 1}}{1 - \theta_j}, \tag{32}$$

where $\pi_{j,t}$ denotes gross inflation in sector j.

[7]For a formal proof see, for instance, Woodford (2003).

3.3 Monetary Policy

We assume that monetary policy follows a Taylor-type rule for the nominal interest rate:

$$\frac{1+R_{L,t}}{1+R_L} = A_{M,t}\left[\pi_{C,t}^{\phi_\pi}\right]^{1-\phi_r}\left[\frac{1+R_{L,t-1}}{1+R_L}\right]^{\phi_r}, \quad \phi_\pi > 1,\ \phi_r < 1, \tag{33}$$

where R_L is the steady-state nominal interest rate, ϕ_π is the coefficient on the inflation target, ϕ_r is the coefficient on the lagged interest rate, and $A_{M,t}$ is a monetary policy shock. In our benchmark calibration, monetary policy targets inflation in the non-durable goods sector and implements interest rate smoothing.

3.4 Market Clearing

Equilibrium in the non-durable goods market requires that production of the final non-durable good equals aggregate demand:

$$Y_{C,t} = \psi C_t + (1-\psi)\widetilde{C}_t. \tag{34}$$

Similarly, equilibrium in the housing market requires

$$Y_{H,t} = \psi\{H_{t+1} - (1-\delta)[1-\mu G_t(\bar{\omega}_t)]H_t\} + (1-\psi)[\widetilde{H}_{t+1} - (1-\delta)\widetilde{H}_t]. \tag{35}$$

Output in the housing sector net of monitoring costs is equal to

$$Y_{H,t}^N = Y_{H,t} - \psi\mu(1-\delta)G_t(\bar{\omega}_t)H_t. \tag{36}$$

Equilibrium in the labor market requires

$$\int_0^1 N_{j,t}(i)di = \psi N_{j,t} \quad j \in \{C,H\}, \tag{37}$$

$$\int_0^1 \widetilde{N}_{j,t}(i)di = (1-\psi)\widetilde{N}_{j,t} \quad j \in \{C,H\}, \tag{38}$$

while the equilibrium in the credit market requires

$$\psi l_t = (1-\psi)\widetilde{l}_t. \tag{39}$$

We define total output as

$$Y_t = Y_{C,t} + p_{H,t} Y_{H,t}. \tag{40}$$

Notice that our measurement of total output reflects variations in the relative price of housing. National account statistics, on the other hand, measure GDP at constant relative prices.

3.5 Exogenous Shocks

There are five exogenous shocks in our model. Aggregate productivity in the two sectors and the monetary policy shock evolve according to the following first-order autoregressive processes

$$\ln A_{C,t} = \rho_C \ln A_{C,t-1} + \epsilon_{C,t}, \quad \rho_C \in (-1,1), \tag{41}$$

$$\ln A_{H,t} = \rho_H \ln A_{H,t-1} + \epsilon_{H,t}, \quad \rho_H \in (-1,1), \tag{42}$$

$$\ln A_{M,t} = \rho_M \ln A_{M,t-1} + \epsilon_{M,t}, \quad \rho_M \in (-1,1), \tag{43}$$

where $\epsilon_C, \epsilon_H, \epsilon_M$ are i.i.d. innovations with mean zero and standard deviation $\sigma_C, \sigma_H, \sigma_M$, respectively, and ρ_C, ρ_H, ρ_M are persistence parameters.

As for the idiosyncratic risk in the housing sector, we follow Bernanke, Gertler, and Gilchrist (1999) and assume that ω_t is distributed log-normally:

$$\ln \omega_t \sim N\left(-\frac{\sigma_{\omega,t}^2}{2}, \sigma_{\omega,t}^2\right). \tag{44}$$

As stated earlier, the mean of the distribution is chosen so that $E_t(\omega_{t+1}) = 1$. We are going to analyze the case where the standard deviation of idiosyncratic housing investment risk exogenously increases. To do this, we assume that the standard deviation of $\ln \omega_t$ is itself an exogenous shock subject to a first-order autoregressive process

$$\ln \frac{\sigma_{\omega,t}}{\sigma_\omega} = \rho_\sigma \ln \frac{\sigma_{\omega,t-1}}{\sigma_\omega} + \epsilon_{\sigma_{\omega},t}, \tag{45}$$

where $\epsilon_{\sigma_{\omega},t}$ is an i.i.d. shock with mean zero and finite standard deviation σ_{σ_ω} and ρ_σ is the serial correlation coefficient. This assumption

Table 1. Benchmark Calibration

Parameter	Value	Description
γ	0.99	Discount factor of Savers
β	0.98	Discount factor of Borrowers
ψ	0.5	Relative size of Borrower group
δ	0.01	Rate of depreciation for housing
ε_C	7.5	Elasticity of substitution for C goods
ε_H	7.5	Elasticity of substitution for H goods
ς	3	Elasticity of substitution across labor inputs
ζ	0.5	Share of Borrower labor in the production function
ξ	0.871	Elasticity of substitution across labor types
α	0.16	Share of housing in consumption bundle
ν	2.5	Disutility from work
η	1	Elasticity of substitution between C and H goods
φ	1	Inverse of elasticity of labor supply
θ_C	0.67	Calvo probability in C
θ_H	0	Calvo probability in H
ϕ_π	1.5	Taylor-rule coefficient on inflation
ϕ_r	0.9	Taylor-rule coefficient on past nominal interest rate
ρ_C	0.9	Serial correlation of productivity shocks in C
ρ_H	0.9	Serial correlation of productivity shocks in H
ρ_M	0	Serial correlation of monetary policy shocks
σ_ω	0.20	Standard deviation of idiosyncratic shocks
μ	0.12	Monitoring cost

captures the fact that housing investment is risky and this risk can change exogenously over time.

Private agents know these exogenous processes and use them to form correct expectations.

4. Steady-State Analysis

4.1 Benchmark Calibration

The parameter values for our benchmark calibration are specified in table 1. We follow Monacelli (2009) in choosing the values for the discount factors for Borrowers and Savers, the rate of depreciation for housing, and the elasticity of substitution between non-durable goods and housing services. The Savers' discount factor γ is set equal to 0.99 and Borrowers' discount factor β is set equal to 0.98. We choose an annual depreciation rate for housing of 4 percentage points, implying $\delta = 0.01$. The elasticity of substitution between non-durable consumption and housing is $\eta = 1$, which implies a Cobb-Douglas specification for the composite consumption index X_t.

U.S. private fixed investment in structures, residential and non-residential, has been on average 5 percent of GDP from 1960 to 2009, while during the period 2000 to 2007 it averaged 8 percent of GDP. We set the parameter α that measures the share of housing in the consumption bundle equal to 0.16, so that the housing sector represents 8 percent of total output at the steady state. The Savers' discount factor pins down the steady-state interest rate at $R_L = 0.0101$ on a quarterly basis. This implies an annual interest rate equal of 4.1 percentage points. The inverse of the Frisch elasticity of labor supply φ is set equal to one, as in Barsky, House, and Kimball (2007) and as typical in the macro literature. As for the parameter ξ that measures the degree of substitutability between hours worked in the two sectors, we set it equal to 0.871. This is the appropriate weighted average of the ξ for Borrowers and Savers estimated by Iacoviello and Neri (2010).

For the degree of price stickiness, we assume that housing prices are fully flexible and set $\theta_H = 0$, which is in line with the empirical estimation of Iacoviello and Neri (2010) and the empirical evidence on price stickiness for durable goods. For non-durable goods, θ_C is set equal to 0.67 to imply that firms in the non-durable sector change their prices on average every nine months. For monetary policy, we set $\phi_\pi = 1.5$ and $\phi_r = 0.9$, which are standard values in the literature. The serial correlation of the monetary policy shock is $\rho_M = 0$. We assume that the Borrower and Saver groups have equal size so that $\psi = 0.5$.

For technology, we follow Calza, Monacelli, and Stracca (2009) and set the elasticity of substitution among intermediate goods ε_j equal to 7.5 in each sector. Labor inputs are imperfect substitutes in production and the elasticity of substitution across Borrowers' and Savers' labor is $\varsigma = 3$. We also assume that the share of Borrowers' labor in the production function ζ is equal to 0.5. The serial correlation of the productivity shocks in the non-durable and housing sectors are chosen to be $\rho_C = 0.9$ and $\rho_H = 0.9$, respectively.

Table 2. Steady State under the Benchmark Calibration

Variable	
Consumption, Borrowers[a]	44.28
Housing Demand, Borrowers[a]	39.40
Hours Worked in C Sector, Borrowers[a]	54.30
Hours Worked in H Sector, Borrowers[a]	54.30
p_H Output H/Total Output	8.09
Loans	2.17
Loan-to-Value Ratio	59.17
Leverage Ratio	80.12
Default Rate on Mortgages[b]	2.34
External Finance Premium[b]	0.41
Mortgage Interest Rate[b]	4.51

Note: The leverage ratio is calculated as $l/(l + w_C N_e + w_H N_H)$.
[a]Expressed as percentage of aggregate level; e.g., Consumption, Borrowers = $\psi C/(\psi C + (1 - \psi)\tilde{C})$.
[b]Annual, percentage points.

Table 2 reports the steady-state values for the benchmark calibration. The loan-to-value ratio is defined in equation (10) and the leverage ratio for Borrowers at the steady state is calculated as

$$\text{Leverage Ratio} = \frac{l}{l + w_C N_c + w_H N_H},$$

which measures the fraction of total expenses financed by loans, namely consumption of C and H plus loan repayment over loans. The leverage ratio captures the dependence of Borrowers from external funding.

We choose the standard deviation of the distribution of $\ln \omega$ at the steady state to match the pre-crisis delinquency rates. In the fourth quarter of 2006, seriously delinquent mortgages represented 2.21 percent of all mortgages.[8] We set $\sigma_\omega = 0.2$ and obtain an annual default rate of 2.34 percentage points. As for the shocks that raise the standard deviation of idiosyncratic housing investment risk, we

[8]See the National Delinquency Survey conducted by the Mortgage Bankers Association.

believe they are persistent, but there is no previous work we can rely on. Christiano, Motto, and Rostagno (2009) estimate the persistence of the idiosyncratic productivity shock for the United States to be 0.85. We set $\rho_\sigma = 0.9$. The median foreclosure price for single-family residences, condominiums, and townhouses in California in the first half of 2006 was 12 percent lower than the median market price of homes sold within the same area without having been previously foreclosed—see Cagan (2006). Hence, we set $\mu = 0.12$, and monitoring costs are 12 percent of the housing value. Interestingly, this is also the value for monitoring cost in Bernanke, Gertler, and Gilchrist (1999). At the steady state, the loan-to-value ratio in our benchmark calibration is almost 60 percentage points. This is lower than 75.7 percentage points, which is the average U.S. loan-to-value ratio between 1973 and 2008. We can raise the steady-state loan-to-value ratio by reducing σ_ω, the steady-state riskiness of loans; however, this is going to reduce the steady-state rate of default. For this reason, we prefer to match the delinquency rate but have a lower loan-to-value ratio than suggested by the data.

At the steady state, the quarterly mortgage rate paid by non-defaulting Borrowers is $R_Z = 0.0111$, which corresponds to an annual rate of 4.51 percentage points. We define the external finance premium at t as $R_{Z,t} - R_{L,t}$, namely the difference between the ex post state-contingent rate paid by non-defaulting household members and the risk-free interest rate, which in our setting is equivalent to the predetermined rate received by lenders on aggregate loans.[9] This premium captures the additional cost that Borrowers must pay for their risky mortgages relative to risk-free borrowing. At the steady state, the external finance premium is equal to 0.41 percentage points on an annual basis. We calculate the empirical counterpart to our external finance premium as the difference between the thirty-year conventional mortgage rate[10] and the interest rate on the U.S. Treasury thirty-year bonds.[11] The average difference between these two annual interest rates between 1977 and 2009 was

[9]Our definition of external finance premium differs from that in Bernanke, Gertler, and Gilchrist (1999), where the premium is the difference between the costs of funds raised externally and the opportunity costs of funds internal to the firm.

[10]See the H-15 Release of the Federal Reserve Economic Data.

[11]See the Economic Report to the President, table B73.

1.5 percentage points. This makes the finance premium of our benchmark model 1 percentage point lower than its empirical counterpart.

For our dynamic analysis, we log-linearize around the deterministic steady state. We solve the resulting linear system of rational expectation equations using standard techniques.

4.2 Low-Leverage Calibration

We additionally consider an economy characterized by higher idiosyncratic housing investment risk but otherwise identical to the benchmark economy described above. For this economy the steady-state standard deviation of the distribution of idiosyncratic housing investment risk is set to $\sigma_\omega = 0.6$. All the other parameters are as in table 1. Higher idiosyncratic housing investment risk implies that more household members are in the left tail of the distribution and that the steady-state rate of default is higher. This raises the external finance premium and reduces mortgage loans, the loan-to-value ratio, and the leverage ratio relative to the benchmark economy. We label this calibration "low leverage" and compare it with the benchmark, "high-leverage" calibration.

Table 3 reports the steady-state values of some endogenous variables in the benchmark and the low-leverage economy. The last column of table 3 reports the percentage point difference between steady-state values in the benchmark and low-leverage economies. Because loans are larger when idiosyncratic housing investment risk is lower, steady-state loans are 173 percentage points higher in the benchmark economy, the loan-to-value ratio is 143 percentage points higher, and the leverage ratio is 34 percentage points higher. At the same time, the mortgage interest rate and the external finance premium are considerably lower in the benchmark economy. As a result, overall economic activity is higher in the economy with the higher leverage ratio.

5. Credit Crunch

5.1 Benchmark Calibration

This section analyzes the dynamic response of the model to an unanticipated increase in $\sigma_{\omega,t}$, the standard deviation of the distribution

Table 3. Benchmark and Low-Leverage Economies: Steady-State Comparison

Variable	Benchmark	Low Leverage	% Difference
Output C	0.5407	0.5399	0.15
Output H	0.1465	0.1419	3.24
Consumption, Borrowers	0.4789	0.4887	−2.01
Consumption, Savers	0.6026	0.5912	1.93
Housing Demand, Borrowers	11.5421	10.5337	9.57
Housing Demand, Savers	17.7524	17.8431	−0.51
Hours Worked, Borrowers in C Sector	0.5879	0.5789	1.55
Hours Worked, Borrowers in H Sector	0.1617	0.1549	4.41
Hours Worked, Savers in C Sector	0.4948	0.5019	−1.41
Hours Worked, Savers in H Sector	0.1361	0.1343	1.37
Loans	2.1747	0.7980	**172.54**
Loan-to-Value Ratio[a]	59.17	24.37	**142.80**
Leverage Ratio[a]	80.12	60.01	**33.51**
Default Rate on Mortgages[b]	2.36	8.21	**−71.22**
External Finance Premium[b]	0.41	2.44	−83.20
Mortgage Interest Rate[b]	4.51	6.54	−31.04

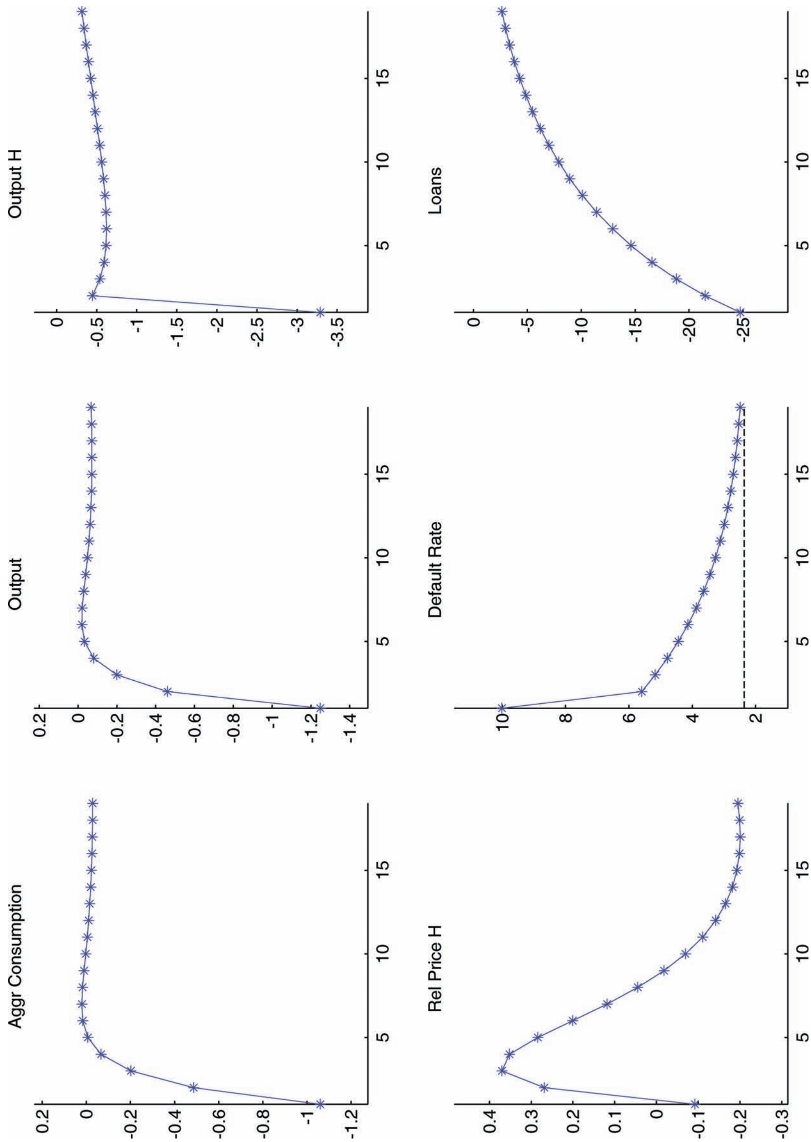
[a]Percentage points
[b]Annual, percentage points.

of idiosyncratic housing investment risk. This increase in risk wants to capture the situation in which loans are made on the basis of an expected distribution for idiosyncratic risk, but the actual distribution turns out to be characterized by a higher standard deviation. In other words, the riskiness of mortgages changes over time and these changes may be persistent. More broadly, exogenous shocks to $\sigma_{\omega,t}$ are an admittedly reduced-form way to capture the entrance in the mortgage market of subprime, or higher risk, debtors. As shown in figure 11 in appendix 2, a mean-preserving increase in $\sigma_{\omega,t}$ implies an increase in the skewness of the distribution of ω_t. Since the log-normal distribution does not take negative values, the lower tail of the distribution becomes thicker. Thus, for the same value of $\bar{\omega}_t$, a higher standard deviation implies a higher cumulative distribution function and therefore a higher default rate on mortgages.

From the third quarter of 2006 to the first quarter of 2010, the delinquency rate on U.S. real estate loans increased from 2.21 to 10.44 percentage points, an increase of 823 basis points. Figure 2 shows the impulse responses of six selected variables to a 40 percent increase relative to its steady-state value in the standard deviation $\sigma_{\omega,t}$ of idiosyncratic housing investment risk. The size of the shock is chosen so as to generate an increase in the default rate of about 800 points. The impulse responses to the same shock but of a larger set of variables are shown in figure 6 in appendix 2. The default rate increases sharply and, together with it, the monitoring costs. Since the mortgage contract guarantees the risk-free interest rate to aggregate loans, the state-contingent mortgage interest rate must increase to satisfy the lenders' participation constraint, which implies an increase in the external finance premium paid by Borrowers. Our model predicts a 150-basis-point increase in the mortgage interest rate and the external finance premium.

The main effects of an increase in the default rate, the monitoring costs, and the external finance premium are the following. First, Borrowers' demand for non-durable goods falls substantially. Because of the mortgage risk shock, Borrowers' financial conditions worsen significantly. More Borrower household members default on their loans and lose their housing stock, while non-defaulting household members pay a higher mortgage interest rate. The overall effect on the budget constraint of the Borrower household is large and negative because the mortgage interest rate paid by non-defaulting household members rises enough to cover the increase in monitoring costs paid by the lenders—see the participation constraint (6). In addition to this, Borrowers experience a tightening in credit conditions due to a reduction in the loan-to-value ratio that reduces their capacity to borrow out of their housing stock. They also experience an increase in real debt via the Fisher effect. Worsening financial conditions force Borrowers to cut consumption of non-durable goods, housing investment, and loans, and to raise hours worked. Savers, on the other hand, are consumption smoothers. In response to a lower real interest rate, they reduce lending, consume more non-durable

Figure 2. Impulse Responses to a 40 Percent Increase in $\sigma_{\omega,t}$



Notes: Default rate is annual and in percentage points. All other variables are percentage-point deviation from steady state. The dotted line is the steady state.

goods, and increase leisure. However, Savers' increase in consumption is small relative to the large cut by Borrowers, and aggregate consumption of non-durable goods falls.

Second, wage differentials arise in equilibrium both across sectors and across groups. Wages in the C sector fall more than those in the H sector for both groups, driven by the large fall in demand for non-durable goods. The resulting wage differential encourages partial switching of hours out of the non-durable into the housing sector. Imperfect substitutability of hours in the utility function prevents sectoral wage differential from disappearing. Borrowers' wages fall more than Savers'. As discussed above, Borrowers, who are credit constrained and considerably hurt by worsened financial conditions, are willing to increase labor supply. As a result, their wages fall in both sectors, but more in the non-durable one. Savers, who are consumption smoothers, increase leisure in response to the decline in the interest rate. Their labor supply drops in the non-durable sector but increases, at least on impact, in the residential one. In fact, the wage of Savers in the H sector rises above steady state. Savers' hours are relatively scarce in the H sector, and the imperfect substitutability of labor inputs precludes firms from equalizing wages across groups.

Third, the housing sector experiences a fall in demand stemming from Borrowers' house downsizing. This reduces housing output, which is shown net of monitoring costs in our graphs. Borrowers need to replenish their housing stock, which contributes to a quick rebound in housing supply. In fact, housing output gross of monitoring costs (not shown in the graphs) increases following the shock. The relative price of houses falls on impact and subsequently rises above steady state. This behavior of the real house price is driven by the dynamics of the real marginal cost in the housing sector, which is an average of Borrowers' (Wage B H) and Savers' (Wage S H) wages in that sector.

Finally, total output in the economy falls, independently of whether housing output is measured net or gross of monitoring costs.[12] The non-durable sector represents more than 90 percent of the economy, and its dynamics drives that of total output.

[12]For consistency, our graphs report total output net of monitoring costs.

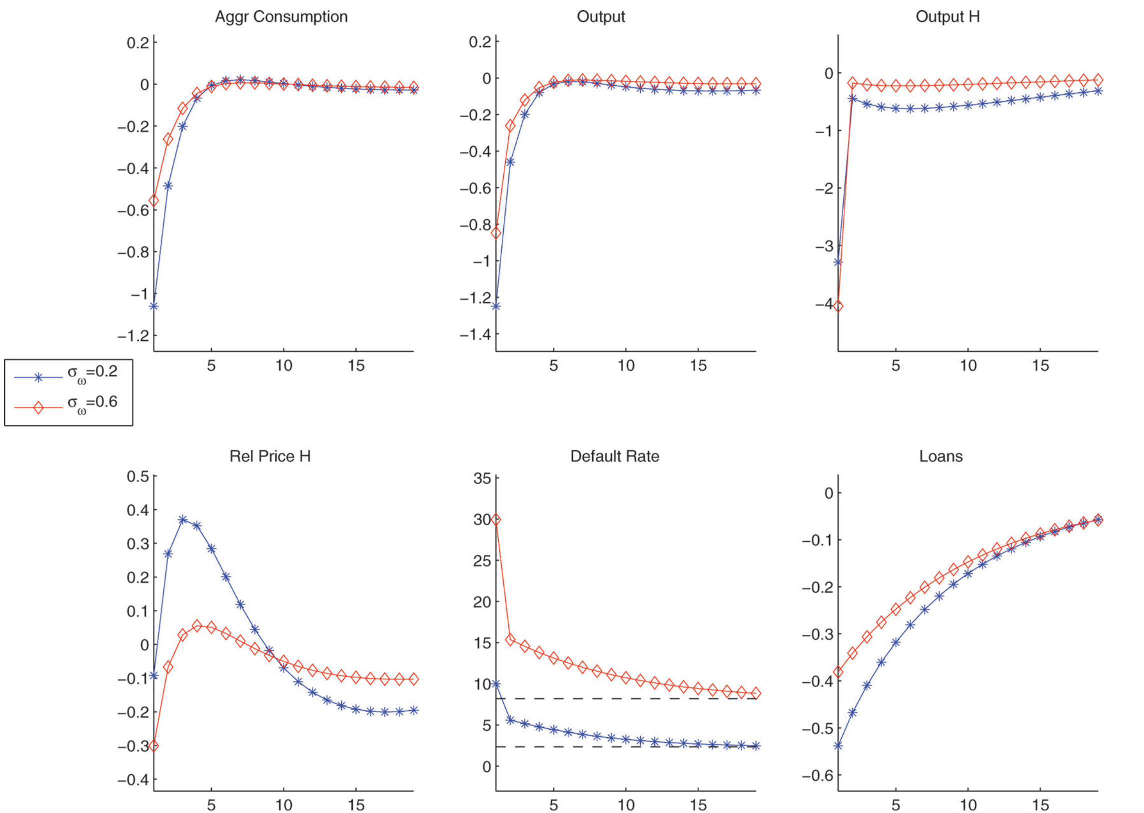
Our model generates a 1.2-percentage-point fall in total output from steady state and a small, short-lived reduction in real housing prices following an increase in mortgage risk. Our model underpredicts the decline in GDP and the real housing price observed in the 2007–09 recession. The rapid rebound in housing demand due to the replacement of monitoring costs seems particularly counterfactual. We speculate that adding a housing rental market may improve the fit of our model. We also believe that the credit crunch that followed the liquidity crisis played a quantitatively important role in the recession of 2007–09. Our model, however, has no capital and therefore no financial intermediation in providing capital to firms. Modeling the financial sector and a financial accelerator in loans to firms are indeed interesting extensions of this framework. Nevertheless, our model captures well the transmission of shocks across sectors, as the non-durable sector is significantly affected by a risk shock in the durable one. Indeed, the impulse responses of our model (figure 2) match, at least qualitatively, those of the VAR (figure 1).[13] As predicted by the model, real consumption, inflation, and the nominal short-term interest rate fall in response to an innovation in serious delinquencies. Interestingly, the model replicates well the hump-shaped response of the real housing price and residential investment to an innovation to delinquencies displayed in the VAR.

5.2 Low-Leverage Calibration

Next we analyze how differences in steady-state leverage ratios imply different dynamic responses to a housing investment risk shock. Figure 3 plots the impulse responses of six selected variables to a 40 percent increase relative to its steady-state value in $\sigma_{\omega,t}$ for the low-leverage economy (line with diamonds) and for the benchmark economy (starred line). Figure 7 in appendix 2 plots the responses of a larger set of variables. The effects of an increase in the standard deviation of idiosyncratic risk in housing investment are amplified in the highly leveraged benchmark economy, which is the economy with

[13]The VAR evidence is relative to a one-standard-deviation innovation in σ_ω, while the data reported above is relative to a 40 percent increase in σ_ω. Moreover, our VAR sample excludes the recent financial crisis.

Figure 3. Impulse Responses to a 40 Percent Increase in σ_ω: Low-Leverage Calibration



Notes: Default rate is annual and in percentage points. Loans are difference from steady state. All other variables are percentage-point deviation from steady state. The dotted line is the steady state.

the lower steady-state standard deviation and default rate. In particular, the credit crunch is deeper and the adverse effects on Borrowers stronger. Loans fall more in the benchmark economy, even though the increase in the standard deviation is actually larger in the low-leverage economy. As a result, Borrowers must cut loans, housing demand, and consumption of non-durable goods more in the economy with high leverage. Aggregate consumption and prices of non-durable goods fall more in the high-leverage economy. The deeper contraction in non-durable demand generates a deeper contraction in total output.

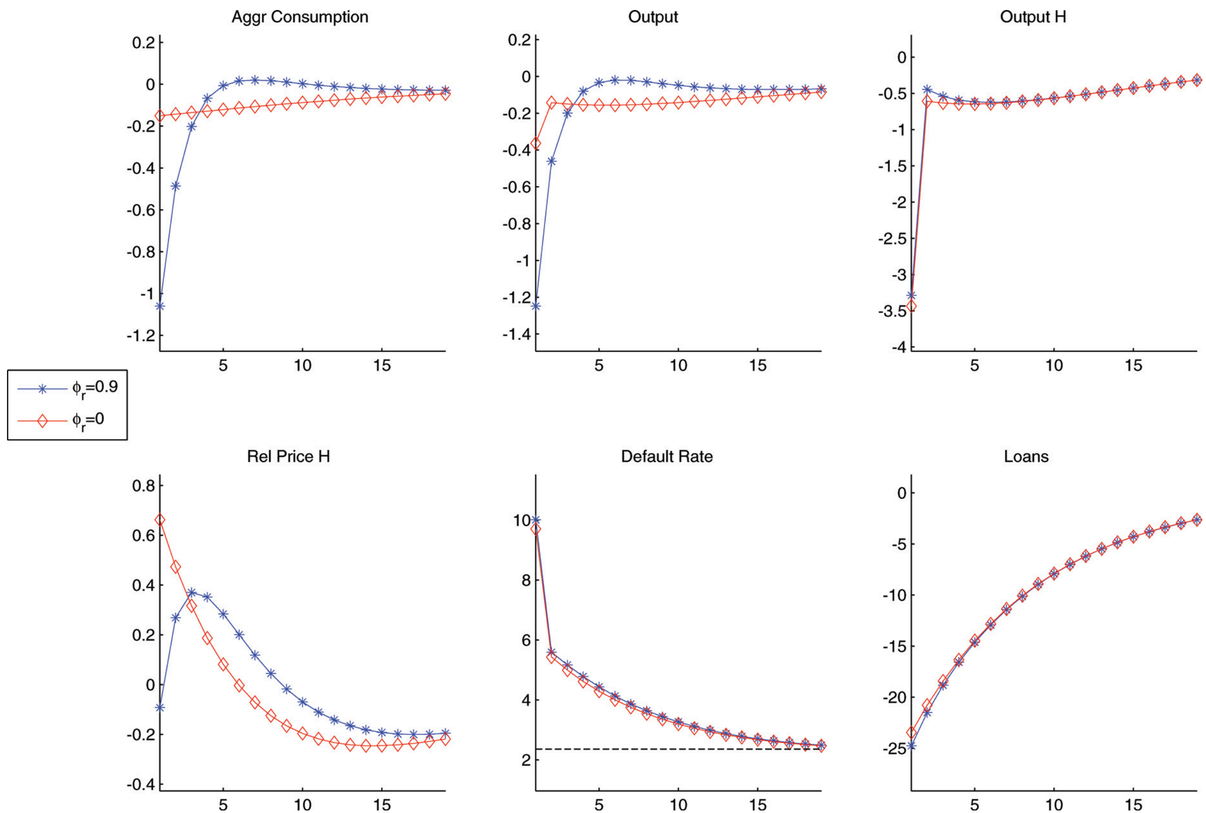
5.3 The Importance of Interest Rate Flexibility

Our benchmark calibration features a large inertia term in the interest rate rule. Here we analyze the implications of adopting less inertial interest rate rules.[14] Figure 4 shows the impulse responses of six selected variables to a 40 percent increase relative to its steady-state value in the standard deviation $\sigma_{\omega,t}$, the same shock analyzed in the previous sections, under alternative values for the inertial term in the interest rate rule. The starred line is the benchmark specification where $\phi_r = 0.9$; the line with diamonds features no interest rate smoothing, $\phi_r = 0$. For all specifications we keep the coefficient on inflation constant and equal to $\phi_\pi = 1.5$. Figure 8 in appendix 2 reports the responses of a larger set of variables.

The negative contemporaneous response of the nominal interest rate is dampened down under the inertial interest rate rule. While the interest rate falls less than 60 basis points when $\phi_r = 0.9$, it falls more than 300 basis points when $\phi_r = 0$. The different response of the nominal interest rate has important implications for non-durable consumption. Under the inertial interest rate rule, Borrowers cut their non-durable goods consumption more and Savers increase it by less, thereby making the negative response of aggregate consumption stronger. Since the nominal interest rate falls less under the inertial rule, Borrowers experience a smaller reduction in their interest rate payments and a larger increase in real debt via the Fisher effect. This makes them reduce non-durable consumption and raise hours

[14]Interest rate rules that respond to output generate similar responses.

Figure 4. Impulse Responses to a 40 Percent Increase in σ_ω and Interest Rate Inertia



Notes: Default rate is annual and in percentage points. All other variables are percentage-point deviation from steady state. The dotted line is the steady state.

worked more, especially in the construction sector. As a result, output in the non-durable sector as well as total output display a deeper contraction under the inertial interest rate rule. Because Borrowers supply more hours in the housing sector when ϕ_r is high, wages in the housing sector fall more and housing prices are more depressed. Interestingly, housing demand, the default rate, monitoring costs, the external finance premium, the loan-to-value ratio, and loans display almost identical responses under different degrees of interest rate smoothing.

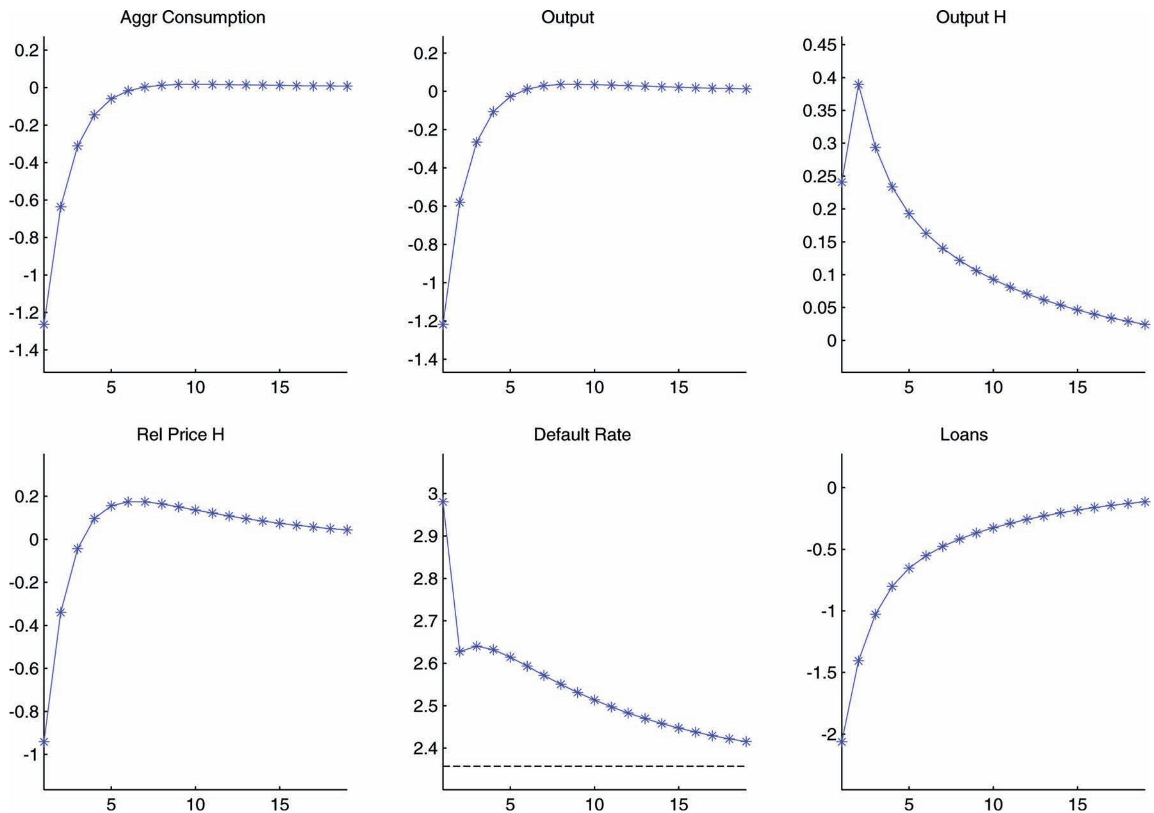
Interest rate rules featuring no inertia display a large degree of interest rate flexibility. The nominal interest rate is cut aggressively in response to an increase in housing investment risk so that the recession in the non-durable sector and in the economy is significantly softened. Notice that strong inertial rules mimic a zero-bound scenario where interest rate cannot be lowered further and the negative effects of a risk shock are amplified.

6. Monetary Policy

6.1 Monetary Policy Shock

Figure 5 illustrates the impulse responses of the model under the benchmark calibration in response to a monetary shock, namely a 25-basis-point increase in the nominal interest rate $R_{L,t}$. Figure 9 in appendix 2 displays the responses of a larger set of variables. Savers, who are consumption smoothers, reduce consumption of non-durable goods in response to higher interest rates. Borrowers are adversely affected in two ways. First, they experience an increase in the cost of borrowing. Second, deflation in non-durable goods raises their real debt via the Fisher effect. Thus, Borrowers reduce mortgage loans, consumption of non-durable goods, and housing services. The fall in the demand for non-durable goods depresses the real wages in the C sector. Hence, both households increase hours in the H sector, thereby reducing the real wage and the relative price of housing. As real housing prices fall, more Borrower household members default. Technically, $\bar{\omega}_{t+1}$, the threshold value of the idiosyncratic shock below which household members do not repay their mortgages, goes up and with it the default rate and monitoring costs. Since fewer Borrower household members repay their

Figure 5. Impulse Responses to a 25-Basis-Point Monetary Shock



Notes: Default rate is annual and in percentage points. All other variables are percentage-point deviation from steady state. The dotted line is the steady state.

loans, the state-contingent mortgage interest rate rises on impact. The nominal interest rate $R_{L,t}$, which is the risk-free rate guaranteed to Savers on outstanding mortgages to be repaid at time t, was set at time $t-1$ and cannot change on impact. As a result, the external financial premium jumps up on impact. The mortgage interest rate increases more than the nominal interest rate, and the external finance premium rises above steady state. The negative wealth effect stemming from higher default, higher mortgage rates, and lower housing value makes Borrowers further cut their consumption of non-durable goods. Aggregate consumption and production of non-durable goods fall. The fall in relative housing prices raises housing demand by Savers, who substitute out of loans into housing. Monitoring costs reduce the existing stock of housing, thereby raising housing demand. Consequently, production in the housing sector increases slightly. Nevertheless, total output falls because the expansion in the construction sector is small and more than compensated by the contraction in the non-durable sector.

A monetary policy shock causes output changes of opposite sign in the two sectors, along the lines of Barsky, House, and Kimball (2007). In their model, a monetary shock that brings down the non-durable sticky-price sector generates an offsetting response in the durable flexible-price sector that leaves GDP unchanged, independently of the relative size of the durable goods sector. Our model shares some features with that of Barsky, House, and Kimball (2007)—in particular, a durable flexible-price sector and a non-durable sticky-price one. The response of our model to a monetary shock displays some similarities to that of Barsky, House, and Kimball (2007). Nevertheless, in our model total output and GDP fall,[15] independently of whether we measure output in the durable sector net or gross of monitoring costs. Due to imperfect substitutability on both the supply and the demand side, labor does not move across sectors so as to close wage differentials. In addition to that, Borrowers in our model are constrained and fail to behave as consumption smoothers. In particular, Borrower housing demand is driven by the fact that housing can be used as collateral for borrowing,

[15] We do not report GDP measured as total output at steady-state relative prices. Nevertheless, GDP would fall in our model.

which makes the shadow value of housing different for Savers and Borrowers.

The result that sectoral output moves in opposite directions in response to a monetary policy shock is at odds with the empirical evidence. Our VAR impulse responses plotted in figure 1 exhibit positive co-movement between consumption and residential investment, confirming the findings of Erceg and Levin (2006). There are two ways to reconcile our model results with this empirical evidence.

The first is to allow for price stickiness in the housing sector. Figure 10 plots the impulse responses of our model for a large set of variables to a 25-basis-point increase in the nominal interest rate under different calibrations. The starred line is the benchmark calibration, where prices in the housing sector are flexible ($\theta_H = 0$). The line with diamonds is the specification with sticky prices in the housing sector ($\theta_H = 0.67$). The line with triangles assumes price stickiness in the housing sector ($\theta_H = 0.67$), perfect substitutability of hours ($\varsigma = 100$ and $\xi = 0$), and a non-inertial monetary policy rule ($\phi_r = 0$, $\rho_m = 0.5$). For all specifications we keep the degree of price stickiness in the non-durable sector constant and equal to $\theta_C = 0.67$. Under price stickiness in housing prices (line with diamonds), residential investment falls on impact.[16] When firms in the durable sector cannot fully adjust prices, labor demand contracts more and wages of Borrowers and Savers in that sector fall more relative to the case with flexible housing prices. The drop in labor income and the decrease in the nominal interest rate induce Savers to cut the supply of loans. Borrowers must therefore reduce their debt, and the value of housing as collateral decreases. Thus, the negative income effect stemming from the larger reduction in Borrowers' wages in the H sector translates into a sharper fall in Borrowers' housing demand. This demand contraction explains the decline in output in the H sector. After the first period, however, residential output rises above steady state. This quick rebound is due to both the imperfect

[16] For simplicity we report only the cases of $\theta_H = 0$ and $\theta_H = 0.67$. Yet, according to our simulations, housing output falls on impact for much lower degrees of stickiness, i.e., for θ_H as low as 0.16. This result is consistent with the findings of Monacelli (2009).

substitutability of hours and the highly inertial response of the nominal interest rate. Once we relax these assumptions, the recovery of residential investment is much slower (see the line with triangles). Higher substitutability of labor supplies and an aggressive reaction of the nominal interest dampen the wage contraction and the initial drop in housing demand, thereby smoothing the behavior of housing investment.

We speculate that another way to achieve output co-movement in our model is to allow for wage stickiness in both sectors, as suggested by Carlstrom and Fuerst (2006). Wages respond less to a monetary shock in the presence of nominal wage stickiness. As a result, firms face a higher marginal cost and contract more the supply of new houses. This fall in the housing supply may more than compensate for the increase in Savers' housing demand that drives the growth of residential output in our simulations. Whether housing output falls or rises is going to depend on the behavior of relative house prices. We leave the introduction of wage stickiness to future research.

7. Conclusions

This paper introduces endogenous default on mortgages in a DGSE model with housing. It analyzes the dynamic response to an increase in the volatility of the distribution of idiosyncratic housing investment risk. We calibrate the size of the shock so as to generate an increase in the default rate of the same magnitude as seen in the data. Under the benchmark calibration, which features an inertial interest rate rule that mimics the zero lower bound, our model predicts a fall in output in both the durable and the non-durable sector. In our model, real GDP per capita falls below steady state by 1.3 percentage points and the housing sector by 3.5 percentage points. In the data, U.S. real GDP per capita fell 3 percentage points below trend in the third quarter of 2009 and residential investment fell almost 17 percentage points. Our model predicts a small reduction in real housing prices followed by a quick rebound. In the data, U.S. real house prices have been below baseline since 2008:Q1 and were 7.3 percentage points below trend at their trough in 2009:Q1. The calibration without inertial monetary policy predicts even smaller output reductions, while the relative price of housing increases on impact and falls below steady state five quarters after the shock. We speculate that some features of our model are responsible for underpredicting the drop in housing investment and house prices. We discuss them below.

If we measure output in the housing sector gross of monitoring costs, the housing sector expands following an increase in mortgage risk. This happens because monitoring costs cause a reduction in Borrowers' housing stock that needs to be replenished rapidly. Housing serves as collateral for Borrowers, and housing services enter the utility function directly. It is not surprising that, following a sharp increase in the rate of default on mortgages and sizable losses in their housing stock, Borrowers seek to quickly rebuild their housing stock, thereby sharply raising housing demand. This result is due to our assumption that the monitoring cost is a fraction of the housing stock whose mortgage has been defaulted on. In reality, foreclosure does not cause a reduction of the housing stock, but it represents a loss of revenues by lenders. An assumption closer to reality could model monitoring costs in terms of loans. A model featuring a rental market may also help reduce the strong and counterfactual surge in housing demand by Borrowers, who can get housing services by renting rather than buying houses. In our model, however, Borrowers demand housing not only because it provides services but also because it can be used as collateral. Even though a rental market provides access to housing services without the need to own a house, it is unlikely it will completely eliminate the increase in Borrowers' housing demand.

Our model predicts a rapid rebound in the construction sector following a large increase in mortgage delinquencies. This is not surprising, as housing prices are perfectly flexible and the only friction in our housing sector is imperfect substitutability of labor types. Introducing lags in production or investment adjustment costs in the construction sector would contribute to generate smoother output responses.

In standard DSGE models with non-durable sticky prices and durable flexible prices, a disturbance that generates a recession in the non-durable sector causes an expansion in the durable sector that leaves GDP unchanged. While our model is non-standard in a number of ways, our housing sector displays some tendency to move in the opposite direction of the non-durable sector—for example, in response to a monetary policy shock. The VAR evidence at the beginning of the paper shows that the non-durable and housing sectors co-move following both a mortgage risk shock and a monetary shock. Imperfect substitutability of hours in the two sectors brings more sectoral co-movement, as it allows for wage differentials that mitigate the incentive of labor to leave the sector with falling wages to enter the booming sector with rising wages. In fact, an earlier version of our model that did not feature imperfect substitutability of hours displayed a large positive response of the housing sector to an increase in mortgage risk, irrespective of whether output in the sector was measured net or gross of monitoring costs. We speculate, however, that wage stickiness may play an important role in bringing the model closer to reality and dampening out the output response in the H sector.

Our model features financial intermediation and a financial accelerator only for the purpose of housing investment. There is no capital in our simple model and therefore no financial intermediation for providing capital to firms. We believe, however, that a decline in financial intermediation has been a crucial contributor to the Great Recession. In particular, the credit crunch—i.e., the tightening of lending conditions faced by firms—that followed the liquidity crisis reduced economic activity and further amplified the effects of the subprime crisis. Introducing a formal banking sector and financial intermediation to provide capital to firms may help to amplify the output effects of financial shocks like the housing investment risk shock considered here.

The mortgage contract in our model is a one-period adjustable-rate mortgage (ARM) contract. Lenders do not take any risk, as they are guaranteed the risk-free rate on the total amount of loans given out to Borrowers. In reality, mortgage contracts are more complex than the contract considered here. In particular, fixed-rate multi-year contracts and ARM contracts with non-standard features may have played a role in setting up the crisis and making it more persistent. At the same time, our mortgage contract is non-recourse, as the Borrower is not personally liable and the lender's recovery is limited to the collateral. Most U.S. states feature non-judicial foreclosure, and our assumption describes well this situation. In other states and countries, however, borrowers may be liable for part of the difference between the value of the loan and that of the collateral, as lenders could pursue borrowers' additional assets or require income payments proportional or equal to such difference. The contract featured in our model does not account for these alternative legal arrangements. It could, however, include income payments in addition to the loss of the housing stock. Modeling the possibility to pursue defaulting borrowers' assets in addition to their houses requires the introduction of an asset that borrowers hold in equilibrium. We leave these interesting extensions to future research.

Appendix 1. Data and Sources

CC: Aggregate consumption. Real personal consumption expenditure (seasonally adjusted, billions of chained 2005 dollars, table 1.1.6), divided by the civilian non-institutional population (CNP16OV, source: Bureau of Labor Statistics). Source: Bureau of Economic Analysis (BEA).

IH: Residential investment. Real private residential fixed investment (seasonally adjusted, billions of chained 2005 dollars, table 1.1.6.), divided by CNP16OV. Source: BEA.

INFLY: Inflation. Percentage change from year ago in the implicit price deflator for the non-farm business sector. Source: Bureau of Labor Statistics (BLS).

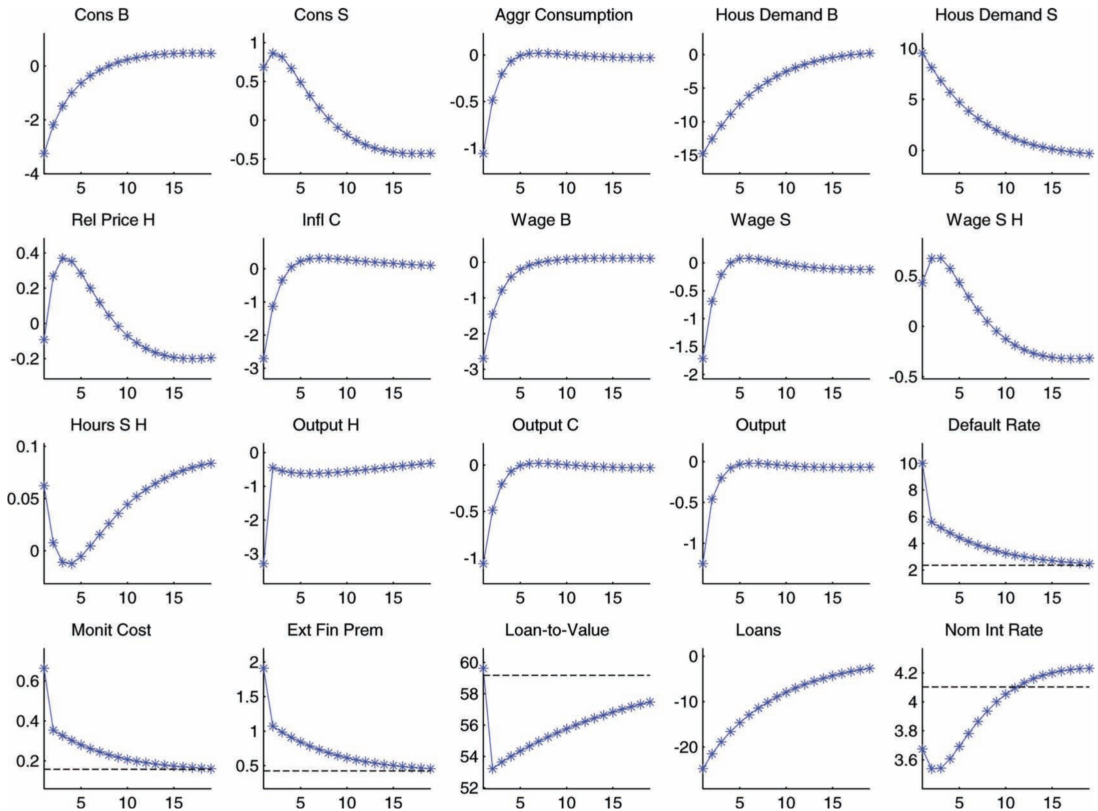
RRY: Nominal short-term interest rate. Three-month Treasury-bill rate (secondary market rate), expressed in yearly units. (Series ID: H15/RIFSGFSM03_NM). Source: Board of Governors of the Federal Reserve System.

QQ: Real house prices. Census Bureau House Price Index (new one-family houses sold, including value of lot) deflated with the implicit price deflator for the non-farm business sector. Source: Census Bureau, http://www.census.gov/const/price_sold_cust.xls.

DEL: Seriously delinquent mortgages, not seasonally adjusted, percentage of total mortgages. Source: Mortgage Bankers Association, National Delinquency Survey.

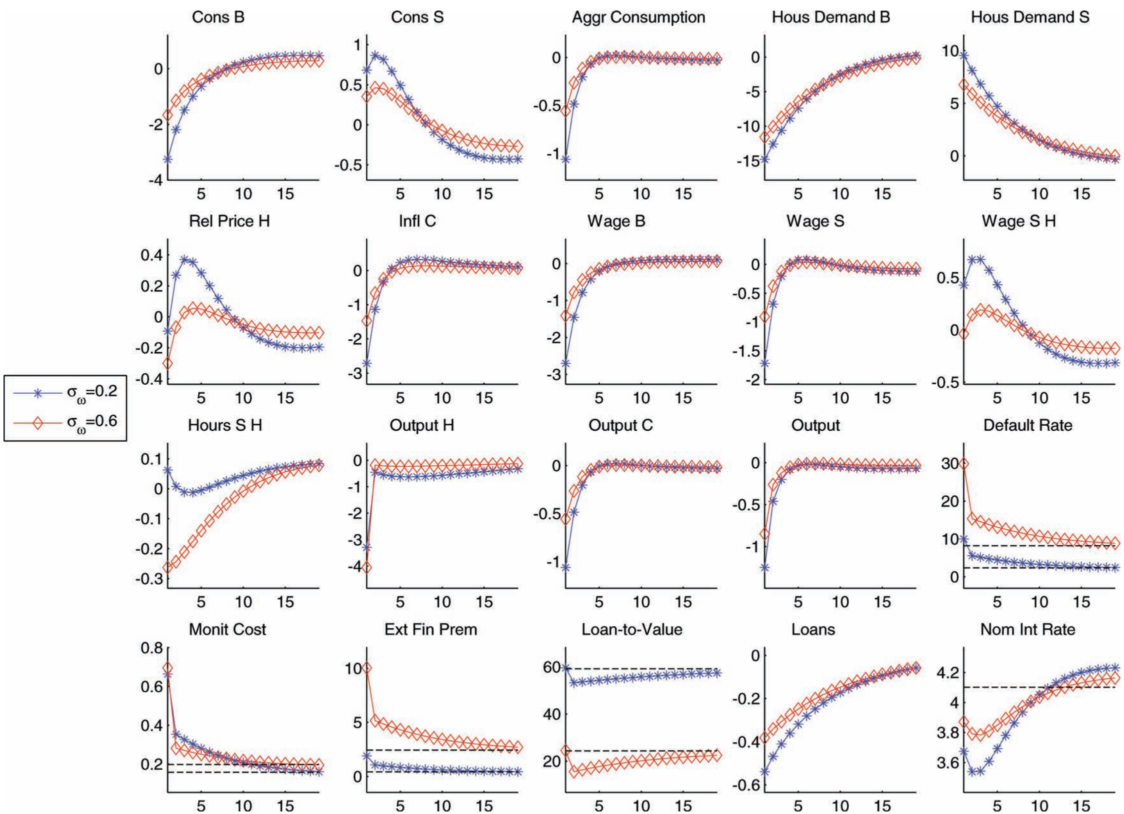
Appendix 2. Figures

Figure 6. Impulse Responses to a 40 Percent Increase in $\sigma_{\omega,t}$: Large Set of Variables



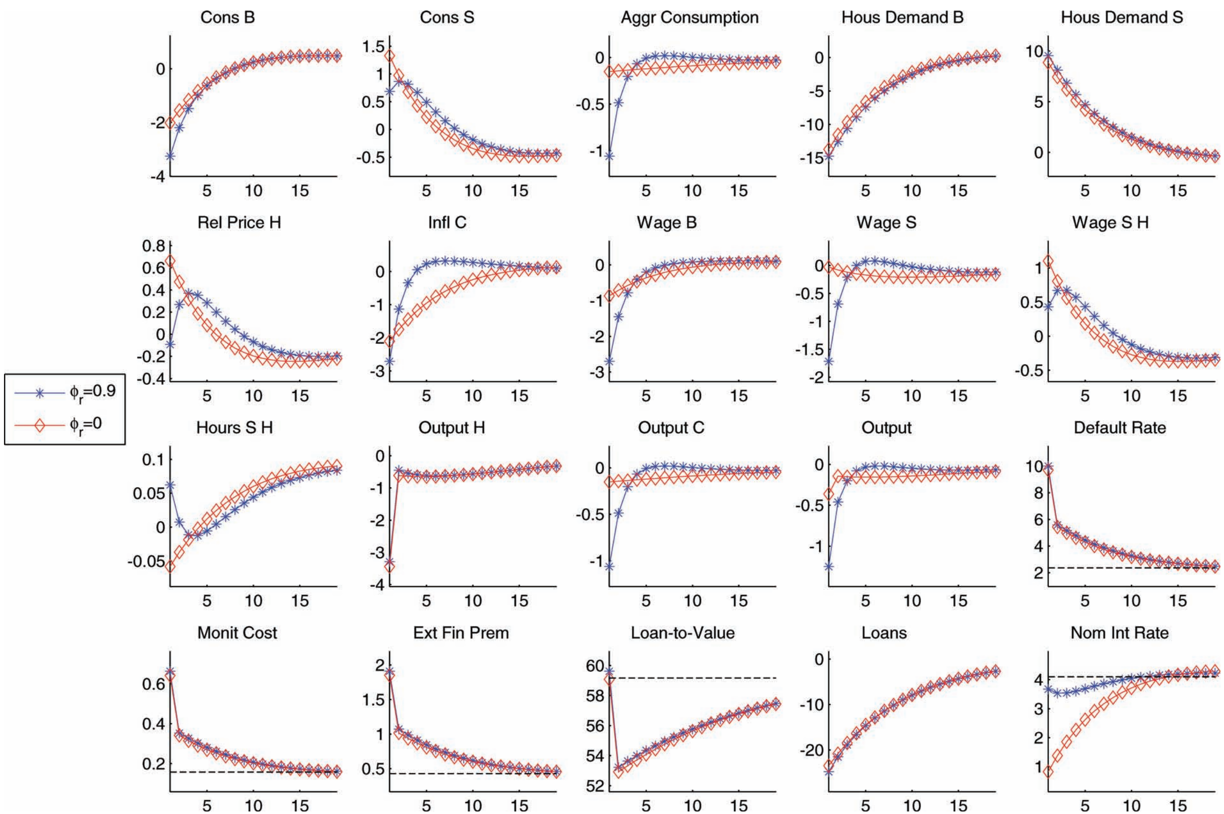
Notes: Default rate, inflation in the H and C sector, external finance premium, mortgage interest rate, and nominal interest rate are annual and in percentage points. Monitoring costs and loan-to-value ratio are in percentage points. All other variables are percentage-point deviation from steady state. Dotted lines are the steady states.

Figure 7. Impulse Responses to a 40 Percent Increase in $\sigma_{\omega,t}$: Large Set of Variables, Low-Leverage Economy



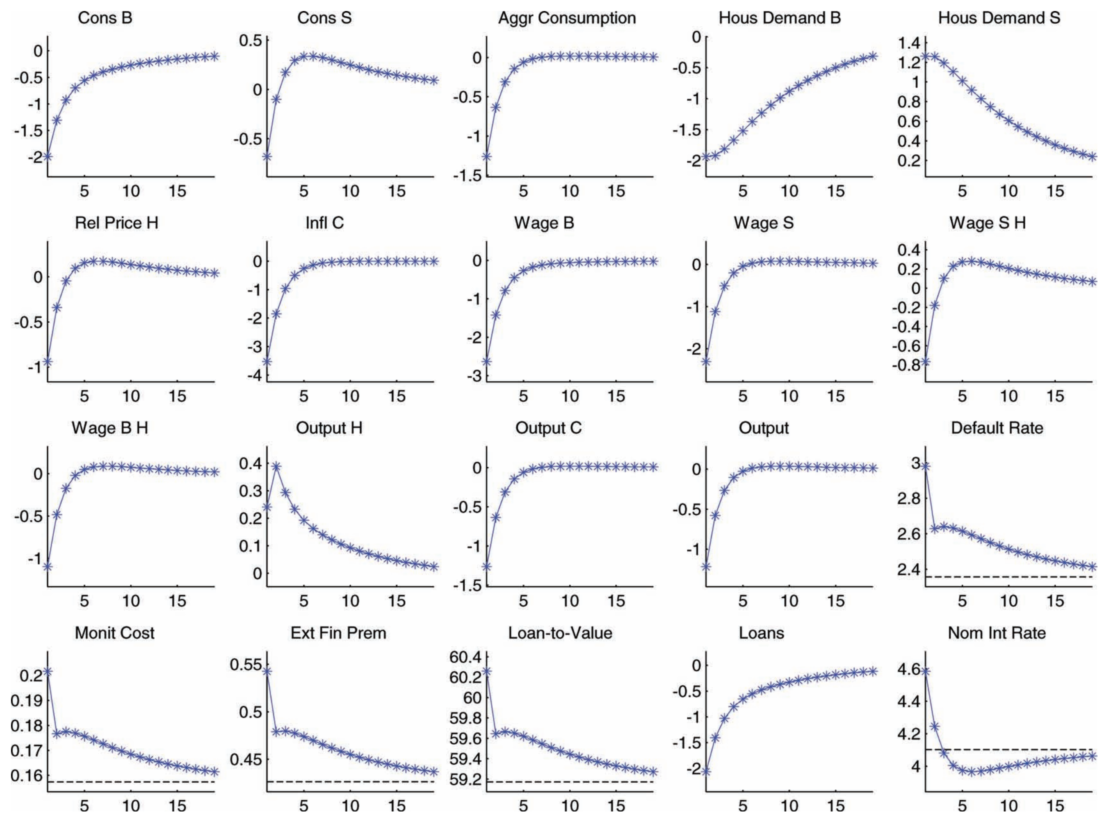
Notes: Default rate, inflation in the H and C sector, external finance premium, mortgage interest rate, and nominal interest rate are annual and in percentage points. Monitoring costs and loan-to-value ratio are in percentage points. All other variables are percentage-point deviation from steady state. Dotted lines are the steady states.

Figure 8. Impulse Responses to a 40 Percent Increase in σ_ω and Interest Rate Inertia: Large Set of Variables



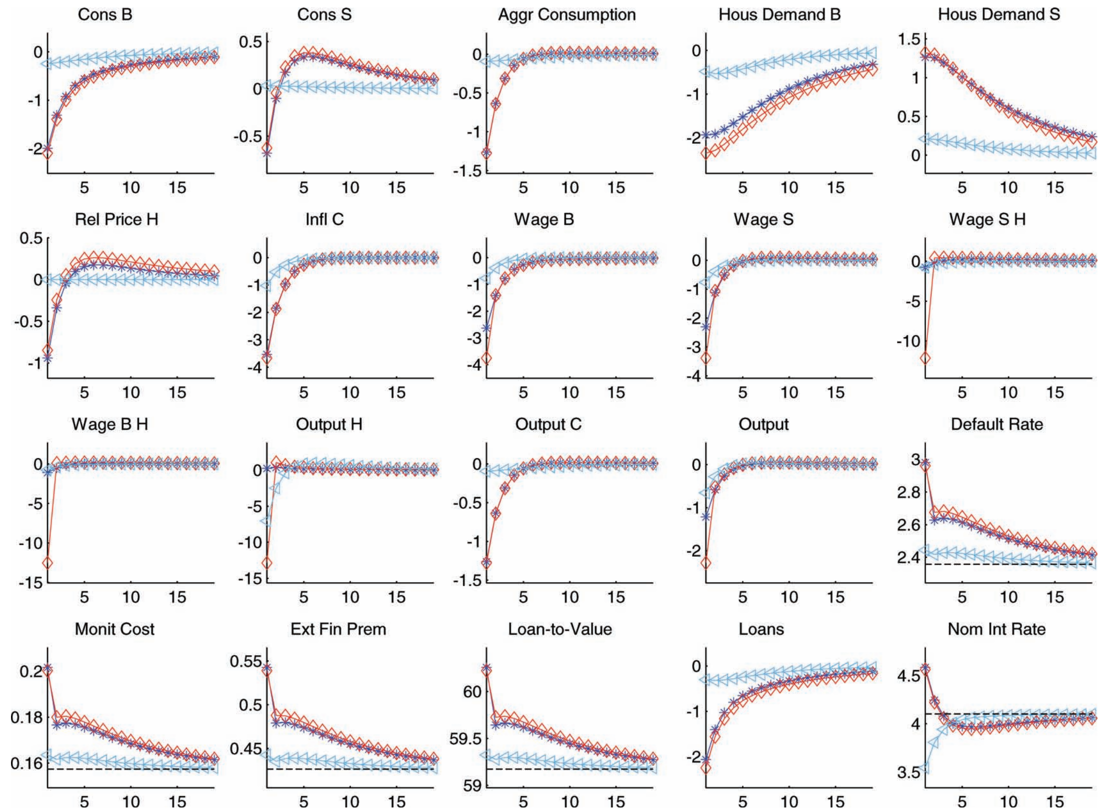
Notes: Default rate, inflation in the H and C sector, external finance premium, mortgage interest rate, and nominal interest rate are annual and in percentage points. Monitoring costs and loan-to-value ratio are in percentage points. All other variables are percentage-point deviation from steady state. Dotted lines are the steady states.

Figure 9. Impulse Responses to a 25-Basis-Point Monetary Shock: Larger Set of Variables



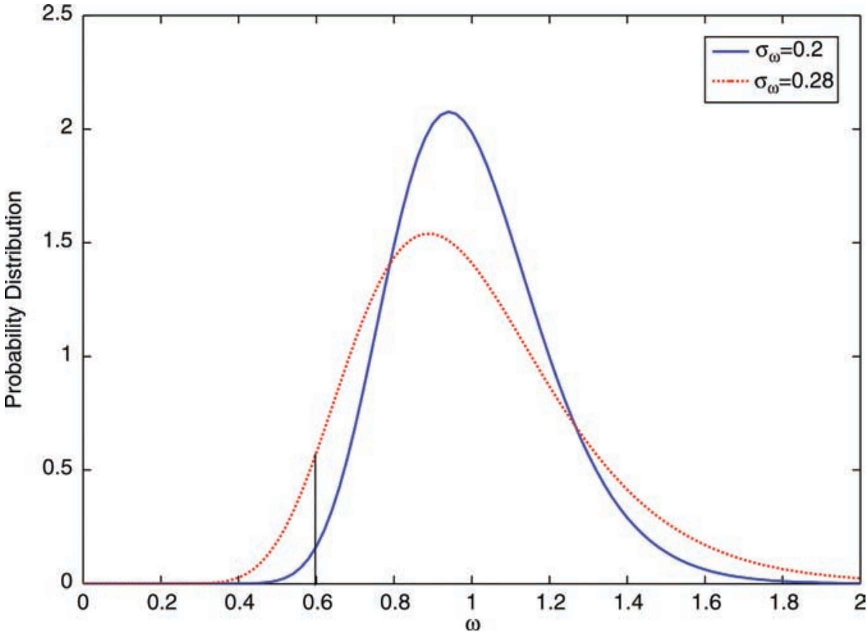
Notes: Default rate, inflation in the H and C sector, external finance premium, mortgage interest rate, and nominal interest rate are annual and in percentage points. Monitoring costs and loan-to-value ratio are in percentage points. All other variables are percentage-point deviation from steady state. Dotted lines are the steady states.

Figure 10. Impulse Responses to a 25-Basis-Point Monetary Shock: Larger Set of Variables



Notes: The starred line is the specification for $\theta_H = 0$. The line with diamonds is the specification for $\theta_H = 0.67$. The line with triangles is the specification for $\theta_H = 0.67$, $\varsigma = 100$, $\xi = 0$, $\phi_r = 0$, and $\rho_m = 0.5$. Default rate, inflation in the H and C sector, external finance premium, mortgage interest rate, and nominal interest rate are annual and in percentage points. Monitoring costs and loan-to-value ratio are in percentage points. All other variables are percentage-point deviation from steady state. Dotted lines are the steady states.

Figure 11. Probability Distribution: An Increase in $\sigma_{\omega,t}$



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Erratum

In the March 2011 issue of the *International Journal of Central Banking*, two equations in "Risky Mortgages in a DSGE Model," by Chiara Forlati and Luisa Lambertini, were shown incorrectly. Below are the corrected equations (28) and (29), which appear on page 304 of the March 2011 issue.

$$-W_{j,t+k} + mc_{j,t+k|t}(i)P_{j,t+k}Y_{j,t+k|t}(i)^{\frac{1}{\varsigma}}A_{j,t+k}^{1-\frac{1}{\varsigma}}\zeta^{\frac{1}{\varsigma}}N_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} = 0, \tag{28}$$

$$-\widetilde{W}_{j,t+k} + mc_{j,t+k|t}(i)P_{j,t+k}Y_{j,t+k|t}(i)^{\frac{1}{\varsigma}}A_{j,t+k}^{1-\frac{1}{\varsigma}}(1-\zeta)^{\frac{1}{\varsigma}}\widetilde{N}_{j,t+k|t}(i)^{-\frac{1}{\varsigma}} = 0, \tag{29}$$

Discussion of “Risky Mortgages in a DSGE Model”

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This is an interesting paper on a timely topic. As the authors argue, the recent global financial crisis has its roots in increased mortgage delinquencies caused by the bursting of the housing bubble in the United States. By what mechanism does such an increase in mortgage delinquencies affect the rest of the economy? And how should policy react to it? To address these issues, the authors develop a dynamic stochastic general equilibrium model with endogenous defaults on mortgage loans.

Specifically, they apply Bernanke and Gertler’s (1989) model of financial constraint to housing investment.[1] The economy produces two kinds of goods: non-durable consumption goods and durable investment goods (“houses”). The value of the housing stock held by each individual is subject to idiosyncratic risk. Mortgage loans take the form of a debt contract, where borrowers who experience a sufficiently large decline in the value of their housing stock declare defaults. In the case of a default, the lender incurs a monitoring cost and seizes the collateral, i.e., the housing stock held by the defaulting borrower. Furthermore, prices of non-durable goods are sticky (prices of housing stock are flexible). Monetary policy is given by an interest rate rule of the Taylor type.

The aggregate shock they focus on is the shock to the volatility of the idiosyncratic shock to the value of housing stock. Its fluctuations

[1]The model of Bernanke and Gertler (1989) is based on the costly-state-verification model of Townsend (1979), and has been elaborated further by Carlstrom and Fuerst (1997) and Bernanke, Gertler, and Gilchrist (1999), among others. Aoki, Proudman, and Vlieghe (2004) is an earlier application of the Bernanke-Gertler model to housing investment.

are interpreted as exogenous changes in the mortgage risk. Based on such a framework, they analyze impulse responses to an exogenous increase in the standard deviation of the idiosyncratic housing risk. An increase in the volatility of the idiosyncratic risk increases the default rate, reduces the supply of loans, and leads to a recession (i.e., both output and consumption fall). These features are roughly consistent with the evidence. The authors argue, however, that there are two counterfactual implications. First, the relative price of housing stock recovers too fast after the shock to the mortgage risk. Second, the decline in the level of output is too small. In addition, they compare interest rate rules with different degrees of interest rate inertia. They find that an increase in the mortgage risk results in a larger recession under a more inertial interest rate rule. Based on this, they argue that interest rate flexibility is important when responding to a shock to the mortgage risk.

The key feature of the model of this paper is to apply the financial friction model of Bernanke and Gertler (1989) to the model of housing investment. An alternative approach would be to apply the collateral constraint model of Kiyotaki and Moore (1997), just as Iacoviello (2005) has done. I'd like to start this discussion by comparing these two approaches.

In this paper, there are two types of households: "Borrowers" and "Savers." Borrowers are less patient than Savers so that, in equilibrium, Borrowers borrow from Savers. Each household consists of a continuum of individual members. Each individual manages a part of the housing stock owned by the household he/she belongs to. The value of the housing stock managed by an individual is subject to an idiosyncratic shock: if he/she manages h_t of housing stock in period t, it becomes $\omega_t h_t$ during the period, where ω_t is i.i.d. across individuals.

By assumption, individuals in Borrowers households obtain loans from lenders (Savers). Consider such an individual who manages housing stock H_t with mortgage loan L_t. It is assumed that a mortgage loan is a debt contract of the following form. Let $R_{Z,t}$ denote the contractual rate of the loan—that is, the rate that applies as long as the borrower is solvent. The Borrower is solvent if the value of the housing stock which he/she manages is greater than the amount that he/she is supposed to repay. Thus, the Borrower is solvent if and only if $\omega_t \geq \bar{\omega}_t$, where $\bar{\omega}_t$ is the threshold value defined by

$$\bar{\omega}_t(1-\delta)P_{H,t}H_t = (1+R_{Z,t})L_t,$$

where $P_{H,t}$ is the price of housing stock and δ is its depreciation rate. If the Borrower experiences a bad enough shock $\omega_t < \bar{\omega}_t$, he/she declares default and the lender seizes the collateral. Thus what the Borrower repays to the lender depends on the idiosyncratic shock ω_t, and is given as follows:

$$\begin{cases} (1+R_{Z,t})L_t, & \text{if } \omega_t \geq \bar{\omega}_t, \\ \omega_t(1-\delta)P_{H,t}H_t, & \text{if } \omega_t < \bar{\omega}_t. \end{cases}$$

In addition, in the case of default, the lender must incur a monitoring cost which is proportional to the value of the collateral he/she is seizing: $\mu\omega_t(1-\delta)P_{H,t}H_t$.

Lenders hold a completely diversified portfolio of loans. Consider a representative Saver who has made loans of total amount L_t in period $t-1$. Let $R_{L,t-1}$ denote the rate of return on his/her portfolio of loans, net of the monitoring cost:[2]

$$\begin{aligned}(1+R_{L,t-1})L_t = &\int_0^{\bar{\omega}_t} \omega_t(1-\mu)(1-\delta)P_{H,t}H_t f(\omega_t)\, d\omega_t \\ &+ \int_{\bar{\omega}_t}^{\infty} (1+R_{Z,t})L_t f(\omega_t)\, d\omega_t, \end{aligned} \tag{1}$$

where $f(\omega)$ is the probability density function. This equation is referred to as the participation constraint of lenders. Note that, gross of the monitoring costs, the amount that the lender receives from Borrowers is $(1+R_{L,t-1})L_t + \mu G(\bar{\omega}_t)P_{H,t}H_t$, where $G(\bar{\omega}) \equiv \int_0^{\bar{\omega}} \omega f(\omega)\, d\omega$.

Now consider a representative Borrowers household that owns housing stock H_t and has mortgage loans L_t at the beginning of period t. Given that the gross amount that the Borrowers household pays to lenders is $(1+R_{L,t-1})L_t + \mu G(\bar{\omega}_t)P_{H,t}H_t$, its flow budget constraint in period t is expressed as

$$\begin{aligned}P_{C,t}C_t + P_{H,t}H_{t+1} - L_{t+1} = &\, W_tN_t + (1-\delta)P_{H,t}H_t \\ &- \{(1+R_{L,t-1})L_t + \mu G(\bar{\omega}_t)P_{H,t}H_t\}, \end{aligned} \tag{2}$$

[2]It is assumed that this rate is predetermined in period $t-1$.

where C_t is consumption of the non-durable good, $P_{C,t}$ is its price, N_t is labor supply, and W_t is the wage rate. The lender's participation constraint (1) can be rewritten as

$$(1 + R_{L,t})L_{t+1} = \Phi(\bar{\omega}_{t+1})(1 - \delta)P_{H,t+1}H_{t+1}, \tag{3}$$

where

$$\Phi(\bar{\omega}) \equiv \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega)\, d\omega + (1 - \mu)G(\bar{\omega}).$$

Note that this constraint may be interpreted as the collateral constraint: the amount that the Borrowers household can borrow (LHS) is limited by the value of its collateral (RHS). The Borrowers household maximizes its lifetime utility subject to the flow budget constraint (2) and the collateral constraint (3).

Now, how different is this model from the Kiyotaki-Moore-Iacoviello (KMI) model? In the KMI model, the Borrowers household's flow budget constraint and collateral constraint would be given respectively as

$$P_{C,t}C_t + P_{H,t}H_{t+1} - L_{t+1} = W_tN_t + (1 - \delta)P_{H,t}H_t - (1 + R_{L,t-1})L_t \tag{4}$$

and

$$(1 + R_{L,t})L_{t+1} = \Phi(1 - \delta)E_tP_{H,t+1}H_{t+1}, \tag{5}$$

where Φ is a constant parameter determining the loan-to-value ratio.

Comparing equations (2)–(3) and (4)–(5), we notice two differences: First, in the model of this paper, the loan-to-value ratio, $\Phi(\bar{\omega}_t)$, is endogenously determined and fluctuates over time, while it is exogenously given in the KMI model. In particular, in this paper's model, the loan-to-value ratio has a close relationship with the default rate, $F(\bar{\omega})$, where $F(\omega)$ is the cumulative distribution function. I find that this is a very attractive feature of the model. The second difference is that $\bar{\omega}$ also directly affects the flow budget constraint (2), because it affects the amount of monitoring costs lenders must incur. These are the differences from the KMI model, which can make the model here more interesting.

Using this framework, the authors try to analyze the effect of an increase in the mortgage risk on the aggregate economy. For this purpose, they assume that the idiosyncratic shock to the value of housing stock, ω_t, has time-varying standard deviation, $\sigma_{\omega,t}$. Specifically, it is assumed to follow an AR(1) process:

$$\ln(\sigma_{\omega,t}) = (1 - \rho_\sigma)\ln(\sigma_\omega) + \rho_\sigma \ln(\sigma_{\omega,t-1}) + \epsilon_{\sigma_{\omega,t}}.$$

Then the authors examine impulse responses of various variables to an innovation to the standard deviation of the idiosyncratic risk, $\epsilon_{\sigma_{\omega,t}}$.

This is a very interesting exercise, which helps to enhance our understanding on how disturbances to the housing market are propagated to the rest of the economy. In the rest of the discussion, I'd like to make some suggestions for further work.

First, land is abstracted from the analysis of this paper. However, evidence suggests that residential land is a very important part of the value of housing stock. It is, for instance, illustrated by Davis and Heathcote (2007), who decompose the aggregate value of the U.S. housing stock into structures and land components over the period 1975–2006. There they find not only that residential land is an important component of the value of the U.S. housing stock, but also that both trend growth and cyclical fluctuations in the price of housing stock are primarily attributable to changes in the price of residential land, rather than changes in the price of structures. Given such evidence, I think it is worth trying to add land to the model of this paper.

Second, in this paper the authors focus on the effects of an increase in the volatility of the idiosyncratic risk to the value of housing. I wonder if this is really what happened at the onset of the recent global financial crisis. Since it plays a central role in the analysis of this paper, I think it would be beneficial to conduct an empirical analysis to see if the volatility of the idiosyncratic risk to the value of housing rose enough to cause the crisis. For instance, in the impulse response analysis of this paper, it is assumed that the standard deviation of the idiosyncratic risk increases by 40 percent.

Third, related to the second comment, many economists have argued that what caused the recent financial crisis was the bursting of the housing bubble. Indeed, the authors themselves provide such a view in the introduction of this paper. Then an interesting question would be how the bursting of the housing bubble affects the economy in the model of this paper. For this exercise we do not need to assume a change in the volatility of the idiosyncratic risk. For instance, let us consider the following kind of a news-shock experiment.[3] Suppose that at a point in time people receive a signal which suggests that the productivity of housing stock increases in some near future; they believe that signal for a while, but at some point they realize that the signal is wrong. This type of news shock will generate a boom and bust of housing prices. It seems to me an interesting exercise to conduct.

Fourth, exploring welfare implications of different monetary policy rules would be an interesting direction of future research. The authors do consider how differently the aggregate variables are affected by the volatility shock under alternative monetary policy rules. However, they do not discuss welfare in this paper. In the model of this paper, there are two distinct types of households: Borrowers and Savers. They presumably have different preferences over monetary policy rules. I think it is interesting to see what kind of conflict of interest they have. In the literature on optimal monetary policy, it is typical to consider a representative household, and thus there is no conflict of interest among households. Such a simplification may be okay in some contexts, but not in others. To me, it appears that explicitly considering such a conflict would become increasingly important.

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[3] Kobayashi, Nakajima, and Inaba (2010) study the effects of a news shock in a related model.

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Monetary Policy and Housing Booms*

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A multitude of factors contributed to the housing booms and crashes experienced in many countries and the ensuing global financial crisis. Much of the existing research on these issues assumes that agents have complete information about the economic environment and form rational expectations. This commentary argues that models with imperfect knowledge and learning provide a potentially rich avenue of research on issues related to housing bubbles and monetary policy. Such models open up an avenue for the endogenous emergence of bubble-like behavior and also provide channels by which monetary and supervisory policies can influence the development of bubbles.

JEL Codes: D44, E52, E83.

The housing booms and busts of the past decade have led economists to take seriously the housing sector and housing finance in macroeconomic models used for monetary policy. The two papers in this volume (Aspachs-Bracons and Rabanal 2011, Forlati and Lambertini 2011) exemplify this renewed appreciation of the role of housing in macroeconomic fluctuations and monetary policy. The basic approach is similar across the two papers. A housing sector is added to the description of preferences and technology in a dynamic stochastic general equilibrium (DSGE) model that incorporates various nominal, real, and financial frictions. Shocks to preferences, technology, and monetary policy are analyzed and alternative monetary policy strategies compared. This research has provided valuable insights into how shocks to fundamentals affect housing, the overall economy, and the proper role of monetary policy to accommodate

*The opinions expressed are those of the author and do not necessarily reflect the views of the management of the Federal Reserve Bank of San Francisco or anyone else in the Federal Reserve System.

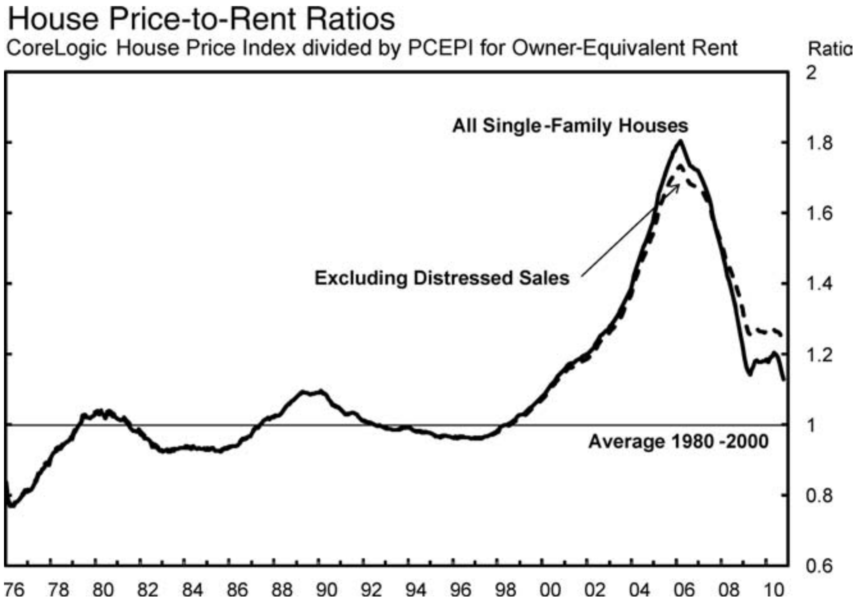
or offset these shocks, assuming agents have full information about fundamentals and form rational expectations.

But, at the end of the day, this line of research sidesteps what I believe is the critical $6 trillion question, where $6 trillion refers to the loss in U.S. household owner-occupied housing wealth between its peak in the fourth quarter of 2006 and the most recent value in the third quarter of 2010. Specifically, what factors contributed the massive run-up in house prices in the United States and many other countries over the past decade and what should monetary and supervisory policies have done about it? In this note I will argue that at least part of the answer to these questions lies outside the complete-information, rational expectations framework assumed in much of the recent research that examines the events of the past decade.

Economists have long recognized and studied the effects of house prices on the macroeconomy. Early contributions include Ando and Modigliani (1963) and Modigliani and Brumberg (1980), who analyzed the wealth effect on consumer spending. This channel is incorporated in many large-scale macroeconometric models that have been and continue to be used at central banks and elsewhere, including, for example, the Federal Reserve Board's FRB/US model (see Brayton et al. 1997). But, in the optimizing-agent DSGE models that have been developed and adopted at many central banks over the past decade, changes in house prices typically have little or no implications for the economy. Indeed, in the absence of financial frictions, these models tell us that house prices, like all asset prices, reflect economic fundamentals and have no effects on consumer spending or anything else, except to the extent that the change in house prices reflects changes in technology or preferences. More generally, in such models, the path of causation runs from the economy to asset prices, not the other way around.

Models with financial frictions provide an important channel by which changes in asset prices affect net wealth and thereby the collateral available for borrowing (see, for example, Bernanke, Gertler, and Gilchrist 1999; Aoki, Proudman, and Vlieghe 2004; Kajuth 2010; and references therein). Such models provide keen insights into the accelerator mechanisms associated with financial frictions and the effects of asset price changes on the availability of credit and on spending and represent a crucial element in future research in this area.

Figure 1. The Great Housing Bubble in the United States



Note: Ratios rescaled such that the average from 1980 to 2000 equals 1.

Despite these important strides in modeling the effects of the housing sector and housing finance on the macroeconomy, most existing macroeconomic models remain largely silent on the sources of and policy implications of extraordinary asset price movements of the type that many countries actually experienced. Figure 1 shows the ratio of house prices to rent in the United States, which reached an all-time peak of 80 percent above its long-run average in March 2006.[1] Between March 2002 and March 2006, the house price-to-rent ratio shot up by more than 10 percent per year on average. Such a massive rise in the house price-to-rent ratio is extremely difficult to generate in an optimizing-agent DSGE model with rational expectations. These models generally preclude the possibility of non-fundamental sources of movements in asset prices, such as bubbles,

[1] According to Shiller's (2005) time series of real U.S. house prices, the house price boom of the 2000s is the largest on record going back to the late nineteenth century.

and by extension preclude a role for monetary or supervisory policy to affect the development of asset price movements not driven by fundamentals.

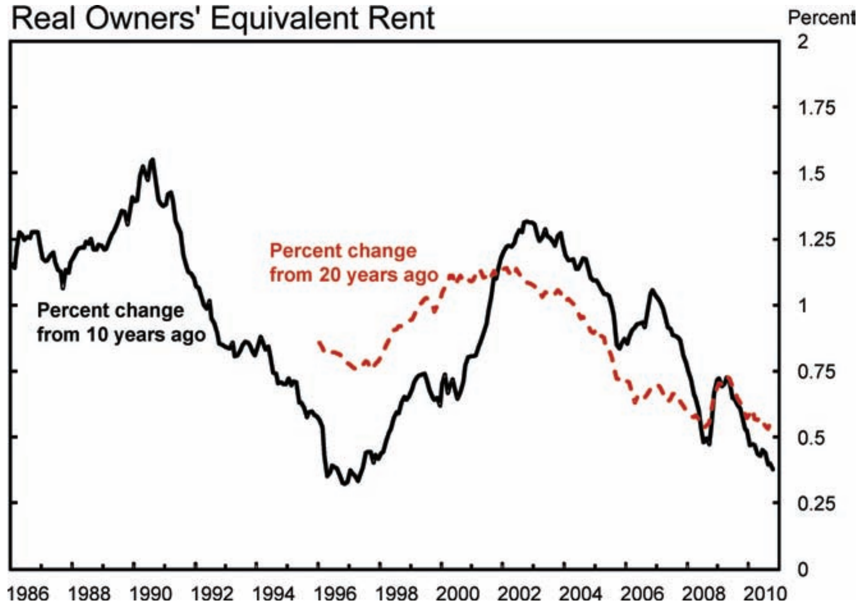
To confront the $6 trillion question in a serious way, we need models that allow asset price bubbles to develop and that include all channels by which monetary and supervisory policies affect asset prices, credit flows, and the real economy. Importantly, this must include endogenous dynamics—not just exogenous shocks—that can lead to asset price and credit run-ups and crashes. One promising approach, studied by Adam, Marcet, and Nicolini (2007) and Lansing (2010), assumes that agents do not have perfect information about economic fundamentals, but instead "learn" through experience. According to this learning approach, agents make rational, optimal decisions based on available information, but the information they possess at any point in time may be sending misleading signals regarding fundamentals.

The learning approach provides a potentially powerful propagation mechanism from economic shocks to large, sustained house price movements. According to standard asset pricing theory, the value of a house depends on the service flow from owning the house (rent), the after-tax interest cost, and expected economic appreciation (after deducting physical depreciation). Under complete information and rational expectations, expected appreciation is tied down by economic fundamentals—in particular, expected future real rents—and a transversality condition. But, in models with learning, agents' forecasts are not necessarily restricted in this way. Instead, agents may use simple forecasting rules based on past empirical observations. Importantly, such models yield asset prices that may deviate substantially from "true" fundamentals, especially following large shocks.

So, what does the learning model have to say about the U.S. housing bubble? First, you need a chain of events to get the ball rolling. In the case of the United States, potential candidates include the strong growth in housing demand that drove up real rents, innovations in mortgage finance, and low mortgage rates.[2] The learning

[2]See also Aspachs-Bracons and Rabanal (2011), who describe fundamental factors that drove up housing demand in Spain. See Taylor (2007) for a discussion of the effects of interest rates on the U.S. housing sector.

Figure 2. Trend Real Rents



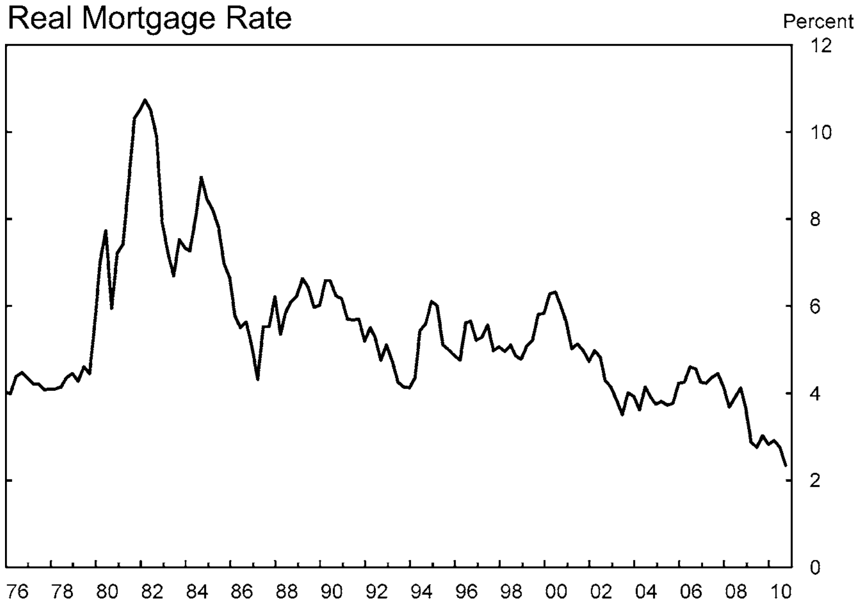
Note: Real OER is the PCE Imputed Rental of Owner-Occupied Non-Farm Housing Price Index divided by the overall PCEPI.

process then propagates and amplifies the shocks, potentially generating much larger swings in house prices than implied by the shift in fundamentals if knowledge were complete.

Trend real house rents accelerated in the late 1990s and early 2000s. The solid line in figure 2 shows the ten-year average annual growth rate of real owner-equivalent rents in the United States. From the mid-1990s to the early 2000s, this figure increased by 1 percentage point. Such an increase in the rate of growth, if viewed as permanent, implies a sizable increase in the equilibrium value of houses.[3] If the trend is instead measured by the twenty-year

[3]For example, consider the textbook Gordon (1959) formula for asset prices. Assume a 6 percent real required return on housing. The implied price-to-rent ratio for 0.25 percent growth in real rents is 17.4. The implied price-to-rent ratio for 1.25 percent growth in real rents is 21.1. Holding the current level of rents constant, the 1-percentage-point increase in the trend growth rate of real rents implies a 21 percent increase in house prices.

Figure 3. Real Mortgage Rates Decline in the 2000s



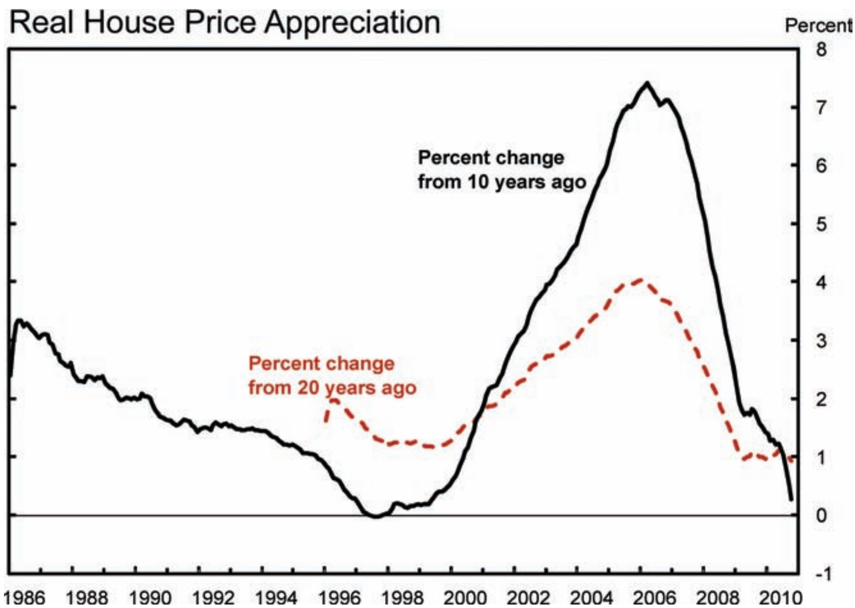
Note: Real mortgage rate is the conventional thirty-year mortgage rate less ten-year expected inflation (PTR) from the FRB/US model.

average annual growth rate (shown by the dashed line), the increase is only about one-third as large, but still implies a significant positive impulse to house prices.

Greater credit availability and low mortgage rates also likely contributed to the rise in house prices during the 2000s. Financial innovation in the form of increased securitization of non-conforming mortgages increased credit availability and arguably reduced costs of borrowing. Moreover, real mortgage rates for conforming loans fell by about a percentage point in the early 2000s, as seen in figure 3.[4] Taken together, these three factors could explain a sizable increase in the equilibrium value of house prices, but one that falls well short of the 80 percent increase in the house price-to-rent ratio actually observed.

[4]In computing real mortgage rates for figure 3, the measure of long-run inflation expectations from the Federal Reserve Board's FRB/US model is used as a proxy for expected inflation.

Figure 4. A Self-Reinforcing Bubble



Note: Real house prices are CoreLogic National Price Index divided by the PCEPI.

It is at this stage of the process that the learning model may play a key role in amplifying and propagating changes in fundamentals into a massive, runaway bubble. Figure 4 shows the ten- and twenty-year average growth rates of real house prices in the United States. Up until the end of the 1990s, trend real house price appreciation averaged about 1 percent. But, once house prices started rising in the late 1990s and early 2000s, this figure rose dramatically. Agents may have incorrectly extrapolated future real house price gains based on past performance. This increase in the expected future rate of house price appreciation raised the perceived value of houses, calling forth a further increase in the market prices for houses, and so on. Of course, in a full-information, rational expectations model, such a process of "irrational exuberance" will not take hold because agents know the true value of assets. But, in a world of imperfect information, agents do not know the true value of asset prices and must base their estimates on the information they have at hand.

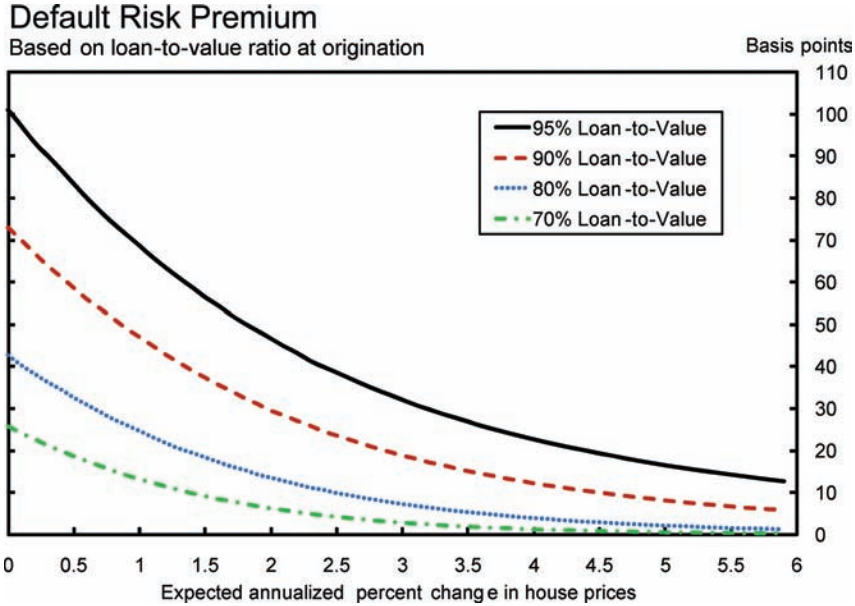
The preceding discussion provides a potential explanation of why households were willing to pay the very high prices for houses during the boom. But why did lenders agree to finance these high prices? After all, if lenders (or investors in mortgage-backed securities) recognized that houses were overvalued, they should have demanded a larger risk premium to compensate them for the higher probability that underwater borrowers would default. The learning model provides a possible answer to this question as well. If lenders followed the same learning algorithm as home buyers and became more optimistic about the rate of growth of future house price increases, then their perception of the probability of default and the associated equilibrium risk premium on mortgages would decline.

According to real option theory, the key factors determining whether a borrower will default are the loan-to-value ratio (LTV) at the time of the loan, the expected trend growth rate and variance of changes in house prices, and the costs associated with default. If the trend growth rate of house prices increases, the probability of default declines and the risk premium demanded by lenders declines as well. Figure 5 plots the risk-neutral risk premium for mortgages as a function of the initial loan-to-value ratios and the expected rate of increase in house prices, using the model of Krainer, LeRoy, and O (2009). As seen in the figure, the risk spread differentials for different LTV ratios shrink as the rate of growth of house prices increases. According to this model, optimistic lenders who base their expectations of future house price gains on past trends rationally make high-LTV loans with very narrow risk premiums.

The perception that defaults would likely remain low was reinforced by the data on mortgage delinquencies. Figure 6 shows the rate of seriously delinquent subprime mortgages over the past decade. During the period of the boom, the subprime delinquency rates remained relatively low. With house prices rising, borrowers were generally able to sell their houses at a profit and pay off their loans, which masked the looming problems in this sector. Of course, in the end, the assumption that real house prices would continue to rise several percent per year proved horribly wrong, and large-scale defaults did occur.

In the learning model, the development of what eventually proves to be a house price bubble is an endogenous reaction to economic events. Therefore, unlike models where the bubble is assumed to be

Figure 5. Real Option Model Implied Risk Spreads

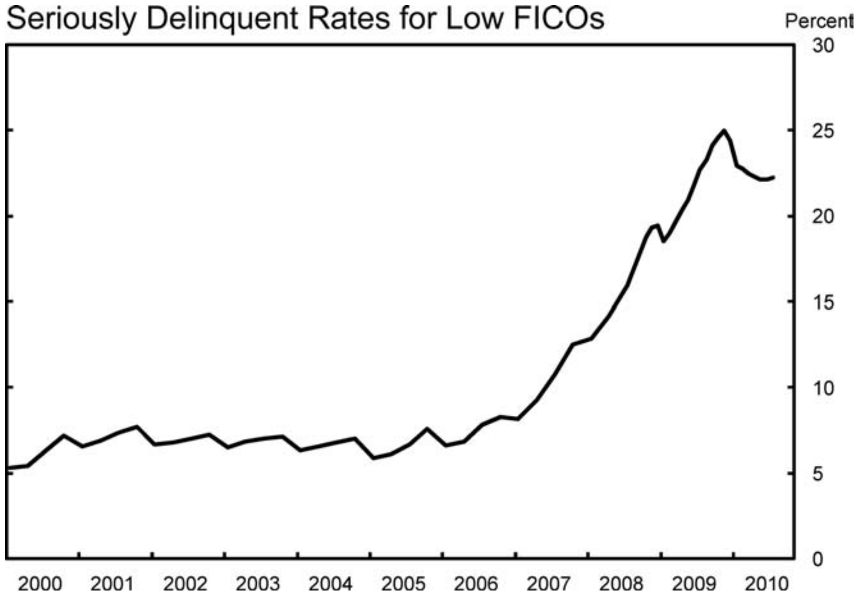


Notes: Based on Krainer, LeRoy, and O (2009). Ten percent volatility of house price changes; six percent borrower rate-of-time preference.

an exogenous process, monetary policy can affect whether a bubble builds up in the first place and can affect the speed at which it deflates. In addition, regulation and supervisory policy can affect the availability of loans during a boom, potentially restricting the supply of funds financing a bubble. Such models raise a number of interesting issues regarding the appropriate design of policies designed to avoid the formation of asset price bubbles and stabilize the economy and the financial system.

A multitude of factors contributed to the housing booms and crashes and the ensuing global financial crisis. There has been an outpouring of research on these issues. Given the extraordinary rise and fall in house prices in several countries and numerous past experiences with bubbles, models with imperfect knowledge and learning provide a potentially rich avenue for research. Such models open up an avenue for the endogenous emergence of bubble-like behavior and also provide opportunities for various policies to influence

Figure 6. The Housing Bubble Masked Looming Problems



Source: LPS Applied Analytics.
Notes: First liens only. Seriously delinquent is sixty-plus days past due or in foreclosure. Low FICO score is FICO less than or equal to 660.

the development of bubbles. Still, there are many unanswered questions about the events of the past decade, and researchers will be plumbing these issues for decades to come.

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