Volume 11, Number 2 March 2015

IJCB

INTERNATIONAL JOURNAL OF CENTRAL BANKING

IJCB
INTERNATIONAL JOURNAL OF CENTRAL BANKING
Volume 11, Number 2 March 2015

International Journal of Central Banking

Volume 11, Number 2 March 2015

*The contents of this journal, together with additional materials provided by article authors, are available without charge at **www.ijcb.org**.*

Copyright © 2015 by the Association of the International Journal of Central Banking. All rights reserved. Brief excerpts may be reproduced or translated provided the source is cited. Consult www.ijcb.org for further information.

The *International Journal of Central Banking* is published quarterly (ISSN: 1815-4654). Online access to the publication is available free of charge at **www.ijcb.org**. Individual print subscriptions are available. Orders may be placed by phone (001 415 974 2035), via fax (001 415 974 2168), or by e-mail (editor@ijcb.org).

Renewals, claims, address changes, and requests for permission to reprint material from this journal should be addressed to:

International Journal of Central Banking
Economic Research Department
Federal Reserve Bank of San Francisco
101 Market Street
San Francisco, CA 94105
USA

Phone: 001 415 974 2035
Fax: 001 415 974 2168
E-mail: editor@ijcb.org

The views expressed in this journal do not necessarily represent the views of the Association of the International Journal of Central Banking or any of its members.

ISSN: 1815-4654

International Journal of Central Banking

Board of Directors

Chairman

Claudio Borio, *Bank for International Settlements*

Board Members

Q. Farooq Akram, *Norges Bank*
Abdulrahman Al-Hamidy, *Saudi Arabian Monetary Agency*
David E. Altig, *Federal Reserve Bank of Atlanta*
Carlos Hamilton Vasconcelos Araujo, *Central Bank of Brazil*
Jan Marc Berk, *The Nederlandsche Bank*
Mohamed Tahar Bouhouche, *Bank of Algeria*
Laurent Clerc, *Bank of France*
Francisco G. Dakila Jr., *Central Bank of the Philippines*
Spencer Dale, *Bank of England*
Jean-Pierre Danthine, *Swiss National Bank*
Michael Dotsey, *Federal Reserve Bank of Philadelphia*
William English, *Federal Reserve Board*
Jiang Feng, *People's Bank of China*
Manuel Ramos Francia, *Bank of Mexico*
Jeffrey C. Fuhrer, *Federal Reserve Bank of Boston*
Kamil Galuscak, *Czech National Bank*
Andrés González Gómez, *Banco de la República*
Niels Lynggård Hansen, *Danmarks Nationalbank*
Dong He, *Hong Kong Monetary Authority*
Heinz Herrmann, *Deutsche Bundesbank*
Tor Jacobson, *Sveriges Riksbank*
Juan F. Jimeno, *Bank of Spain*
George A. Kahn, *Federal Reserve Bank of Kansas City*
Ali Hakan Kara, *Central Bank of Turkey*
Christopher Kent, *Reserve Bank of Australia*
Jun Il Kim, *Bank of Korea*
Evan Koenig, *Federal Reserve Bank of Dallas*
Ana Christina Leal, *Bank of Portugal*
Choy Keen Meng, *Monetary Authority of Singapore*
John McDermott, *Reserve Bank of New Zealand*
Maurice McGuire, *Central Bank of Ireland*
Deepak Mohanty, *Reserve Bank of India*
Vyacheslav Morgunov, *Central Bank of Russian Federation*
Alberto Naudon, *Central Bank of Chile*
Edward Offenbacher, *Bank of Israel*
Fabio Panetta, *Bank of Italy*
Thórarinn G. Pétursson, *Central Bank of Iceland*
Cristian Popa, *National Bank of Romania*
Ivan Ribnikar, *Bank of Slovenia*
Lawrence Schembri, *Bank of Canada*
Sam Schulhofer-Wohl, *Federal Reserve Bank of Minneapolis*
Mark Schweitzer, *Federal Reserve Bank of Cleveland*
Frank Smets, *European Central Bank*
Jan Smets, *National Bank of Belgium*
Daniel Sullivan, *Federal Reserve Bank of Chicago*
Altin Tanku, *Bank of Albania*
Juha Tarkka, *Bank of Finland*
George Tavlas, *Bank of Greece*
Joseph Tracy, *Federal Reserve Bank of New York*
Dobieslaw Tymoczko, *National Bank of Poland*
Christopher Waller, *Federal Reserve Bank of St. Louis*
Kenichirou Watanabe, *Bank of Japan*
John Weinberg, *Federal Reserve Bank of Richmond*

Editorial Board

Managing Editor

John C. Williams
Federal Reserve Bank of San Francisco

Co-editors

Pierpaolo Benigno
LUISS Guido Carli

Michael B. Devereux
University of British Columbia

Harrison Hong
Princeton University

Loretta Mester
Federal Reserve Bank of Cleveland

Rafael Repullo
CEMFI

Stephanie Schmitt-Grohe
Columbia University

Associate Editors

Patrick Bolton
University of Columbia

Michael D. Bordo
Rutgers University

Mark Carey
Federal Reserve Board

Pierre Collin-Dufresne
University of Columbia

Guy Debelle
Reserve Bank of Australia

Douglas W. Diamond
University of Chicago Graduate School of Business

Francis Diebold
University of Pennsylvania

Michael Dotsey
Federal Reserve Bank of Philadelphia

Darrell Duffie
Stanford University

Jordi Galí
Centre de Recerca en Economia Internacional (CREI)

Marvin Goodfriend
Carnegie Mellon University

Michael B. Gordy
Federal Reserve Board

Luigi Guiso
European University Institute

Andrew G. Haldane
Bank of England

Takatoshi Ito
University of Tokyo

David Lando
Copenhagen Business School

Philip Lane
Trinity College Dublin

Francesco Lippi
University of Sassari

Carmen M. Reinhart
Harvard Kennedy School

Eli M. Remolona
Bank for International Settlements

Hélène Rey
London Business School

Jean-Charles Rochet
University of Toulouse

Andrew K. Rose
University of California, Berkeley

Klaus Schmidt-Hebbel
Organisation for Economic Co-operation and Development (OECD)

Lars E.O. Svensson
Sveriges Riksbank

Jürgen von Hagen
University of Bonn

Ernst-Ludwig von Thadden
University of Mannheim

Tsutomu Watanabe
University of Tokyo

Advisory Board

Franklin Allen
The Wharton School of the University of Pennsylvania

Charles Goodhart
London School of Economics

Hyun Shin
Princeton University

Kazuo Ueda
University of Tokyo

Carl E. Walsh
University of California

Michael Woodford
Columbia University

John Taylor
Stanford University

Inflation Expectations and the News[*]

Michael D. Bauer
Federal Reserve Bank of San Francisco

This paper provides new evidence on the importance of inflation expectations for variation in nominal interest rates, based on both market-based and survey-based measures of inflation expectations. Using the information in TIPS break-even rates and inflation swap rates, I document that movements in inflation compensation are important for explaining variation in long-term nominal interest rates, unconditionally as well as conditionally on macroeconomic data surprises. Daily changes in inflation compensation and changes in long-term nominal rates generally display a close statistical relationship. The sensitivity of inflation compensation to macroeconomic data surprises is substantial, and it explains a sizable share of the macro response of nominal rates. The paper also documents that survey expectations of inflation exhibit significant co-movement with variation in nominal interest rates, as well as significant responses to macroeconomic news.

JEL Codes: E43, E44, E52.

1. Introduction

Are changes in expected inflation an important driver for variation in long-term nominal interest rates? To understand the driving forces behind changes in nominal rates is crucial for academic researchers and policymakers, since it reveals how economic agents form expectations about policy and inflation, how risk premia vary over time, and how real and nominal forces affect economic incentives. Macroeconomic data releases are a major source of volatility and lead to pronounced responses of the nominal term structure of interest rates (Balduzzi, Elton, and Green 2001; Gürkaynak, Sack, and Swanson 2005; Bauer 2014). This paper provides new evidence, using both

[*]Author e-mail: michael.bauer@sf.frb.org.

market-based and survey-based measures of expected inflation, that variation in inflation expectations contributes importantly to the variability in both short-term and long-term nominal interest rates.

The Taylor-rule literature has demonstrated that movements in policy rates can be accurately described by a simple policy rule in which the nominal short rate is a linear function of inflation and output.[1] In estimated Taylor rules, the policy response to current inflation is typically found to be very pronounced (Taylor 1999; Clarida, Gali, and Gertler 2000). There is a tight statistical relationship between current inflation and current short-term interest rates.[2] In light of this fact, one might expect that expectations of future nominal short rates are closely related to expectations of future inflation. This would imply that a large share of variation in nominal long-term rates is explained by variation in future inflation. However, if the policy rule is credible and satisfies the Taylor principle, i.e., exhibits a positive response of real short rates to inflation, and if inflation expectations are anchored, then shocks affecting current output and inflation will be undone by monetary policy. In that case, long-term inflation expectations will be largely unaffected by current shocks. It is ultimately an empirical question how variable inflation expectations are and how much they contribute to the variability in nominal rates. The answer to this question has implications for the effectiveness of monetary policy. Highly variable inflation expectations would indicate the lack of a credible inflation target of the central bank.

One way to address this issue is to investigate the response of inflation expectations to macroeconomic data surprises. Unfortunately, inflation expectations are not easy to measure. Several studies have used financial market data to learn about the response of inflation expectations to macro surprises. Gürkaynak, Sack, and Swanson (2005) find that in the United States, far-ahead nominal forward rates are quite sensitive to news, and argue that variation in inflation expectations and shifts in the central bank's implicit inflation likely

[1] After Taylor's (1993) original paper, there have been numerous studies on this topic; for a survey, see Orphanides (2008).

[2] Additionally, the literature about the Fisher effect shows that at low frequencies both short- and long-term interest rates move together with actual inflation—see specifically Wallace and Warner (1993).

explain this result. Gürkaynak, Levin, and Swanson (2010) come to a similar conclusion based on an analysis of the sensitivity of forward inflation compensation—the difference between nominal forward rates and real forward rates from the Treasury Inflation-Protected Securities (TIPS) market. In contrast, Beechey and Wright (2009), henceforth BW, estimate only small responses of forward inflation compensation to real-side macroeconomic news, and attribute most of the impact of such news on nominal rates to the response of real rates.

To shed some light on these contradicting findings, this paper revisits this evidence and carefully investigates the role of inflation compensation for explaining movements in nominal interest rates. While the studies cited above have focused on TIPS break-even inflation (BEI) rates—the spread between nominal rates and TIPS real rates—as a measure of inflation compensation, I also include inflation swap (IS) rates in the analysis. These instruments provide additional useful information about inflation compensation, which is unobserved due to market frictions and liquidity effects. I present results for both BEI and IS rates, as well as for an additional, novel measure of inflation compensation, which incorporates information from both sources and includes a liquidity adjustment.

There is a close statistical relationship between inflation compensation and long-term nominal rates. Unconditional correlations between daily changes in inflation compensation and in nominal rates are generally quite high, independent of the sample, frequency, or measure of inflation compensation. This correlation has varied over time, and its exact magnitude slightly differs between alternative measures of inflation compensation, but the overall picture that emerges is one of a quite strong co-movement. The high correlations suggest that variability in inflation compensation was important for variation in nominal interest rates. An additional point is that toward the end of the sample, correlations with nominal rates decrease significantly, which may be the result of the introduction of an explicit inflation target by the Federal Reserve and a consequently declining role for variation in inflation expectations most recently.

We are ultimately more interested in the response of interest rates to news about economic fundamentals than in unconditional correlations. I document that inflation compensation, no matter how it is measured, exhibits strong sensitivity to macroeconomic surprises, both for price-level news and real-side news. This holds true for long-term yields as well as far-ahead forward rates. Surprises about non-farm payrolls, a major source of economic news and driver of nominal interest rates, have significant and sizable effects on inflation compensation. Overall, inflation compensation appears to be a quantitatively important factor for explaining the high sensitivity of long-term nominal rates to macro news.

While consistent with other studies in this literature, my findings about the sensitivity of forward inflation compensation to real-side macro news stand in contrast to those of BW, who find very little such sensitivity and conclude that "the vast majority of the sensitivity is concentrated in real rates." I drill down into the reasons for the different findings, and show that focusing on intraday responses of TIPS break-even rates, as BW do, may partly mask the sensitivity to real-side macro news. This is due to a slightly delayed response to the announcements. I argue that event studies using intraday changes in asset prices, while having a lot of potential to increase precision and avoid unnecessary noise, should normally be complemented by analysis using daily changes. If we find significant results using daily event windows, and do not using intradaily event windows, then we may want to carefully explore the data for potential delays in asset price responses.[3] Another reason for differences between my results and those of BW is that they include the financial crisis in their sample, a period during which TIPS BEI rates may not have reflected inflation compensation very accurately due to variations in liquidity premia in Treasury markets.

The presence of inflation risk premia is a concern, because movements and sensitivity of inflation compensation may be partly due to the behavior of such risk premia. However, there is evidence that risk premia primarily move at lower frequencies, which suggests that they would be largely differenced out in the high-frequency analysis described above. Furthermore, risk premia appear to behave countercyclically, whereas the response of inflation compensation to

[3]Statistically significant delayed responses do not necessarily imply arbitrage opportunities, for two reasons. The response may be too small, given the presence of transaction costs, to be taken advantage of in practice. And the required trading position to profit from such a pattern may be quite risky.

macroeconomic news is procyclical. It is unlikely that risk premia are a major factor responsible for these results. However, to guard against this possibility, the paper also investigates the behavior of survey-based inflation expectations.

Survey expectations of future inflation are available from different sources. In my analysis I focus on the monthly Blue Chip Economic Indicators survey and the quarterly Survey of Professional Forecasters. In addition to near-term inflation expectations, both also include long-term expectations (although these are only semi-annual for Blue Chip). As for the market-based inflation expectations, I consider the unconditional relationship between nominal rates and inflation expectations, as well as their behavior conditional on macroeconomic news, under the constraints that the frequency is lower and the horizons are determined by the survey designs. The correlations between changes in nominal interest rates and survey expectations of inflation are significant for short horizons, and in some cases for long horizons. The magnitudes of the correlations of nominal rates with inflation expectations are similarly high as those with inflation compensation at the same frequencies. This indicates that the co-movement of inflation expectations and nominal interest rates is substantial, and that it is expectations and not risk premia that explain the co-movement with inflation compensation.

The paper is the first to estimate the sensitivity of survey-based inflation expectations to macro news. To do so, I cumulate macro surprises over the monthly or quarterly observation windows. Naturally, these long windows substantially lower the precision of the estimated sensitivities, since a host of news and noise that we cannot control for also affect agents' expectations over these intervals. However, the results still show significant responses, both economically and statistically, of several different survey measures of inflation expectations to macroeconomic surprises. The regression R^2 is around 20 percent, which is substantial given the amount of outside news during such a long observation period, and it is almost as high as for the regressions of nominal interest rates on macro news. The macro surprises are jointly significant for all but one expectations measure. Several estimated coefficients are significant and sizable, and most have the expected sign. Overall, this regression-based evidence points to significant sensitivity of inflation expectations to macro news, and to an important role of inflation expectations in explaining the sensitivity of nominal rates. While the evidence is stronger for expectations at short horizons, there is also some evidence for the variability of long-term inflation expectations.

Taken together, the evidence presented in this paper suggests that long-term inflation expectations display economically important variation, and that they play a substantial role in explaining the variability of long-term nominal interest rates and their responses to macro news. One consequence of this conclusion is that a better anchoring of long-term inflation expectations, lowering their volatility and sensitivity to macroeconomic news, would likely reduce the variability of long-term interest rates. Hence, well-anchored inflation expectations have important economic benefits, not only in terms of reduced uncertainty about future inflation but also in terms of lower variability of asset prices. This is a strong argument in favor of explicit inflation targets for the conduct of monetary policy, in order to better anchor inflation expectations.

2. Market-Based Measures of Inflation Expectations

A convenient and widespread approach for obtaining estimates of inflation expectations is to use financial market data. The crucial concept is inflation compensation, which is the additional yield that investors require to cover expected future inflation and the riskiness due to the uncertainty of future inflation:

$$i_t^n = r_t^n + IC_t^n \tag{1}$$

$$= r_t^n + n^{-1} \sum_{i=1}^{n} E_t \pi_{t+i} + IRP_t^n. \tag{2}$$

The nominal interest rate for a zero-coupon bond of maturity n, i_t^n, is the sum of the real interest rate for the same maturity, r_t^n, and inflation compensation, IC_t^n. Despite the availability of inflation-indexed fixed-income securities, such as TIPS bonds in the United States, the real interest rate and inflation compensation are not observed without error. Due to differences in liquidity premia between nominal and inflation-indexed bond markets, the difference between observed nominal and real yields will be a noisy measurement of inflation compensation. To guard against this issue, the analysis is carried out using alternative estimates of inflation compensation.

Due to the risk of changes in inflation, inflation compensation generally contains an inflation risk premium. Equation (2) is the generalized Fisher equation, expressing the nominal rate as the sum of the real rate, expected future inflation—π_t is the continuously compounded rate of inflation between $t-1$ and t—and an inflation risk premium, IRP_t^n. The ultimate goal of this paper is to learn about the importance of inflation expectations, the second term in equation (2), for variation in long-term nominal rates. To obtain evidence about inflation expectations based on an analysis using inflation compensation, one needs to either resort to a model for estimating the risk premium, as in Christensen, Lopez, and Rudebusch (2010) or D'Amico, Kim, and Wei (2010), or make additional assumptions about the behavior of this risk premium. Because estimates of the inflation risk premium are highly uncertain and model dependent, I focus on documenting patterns in inflation compensation and do not attempt to correct for a risk premium. Empirical evidence suggests that risk premia move slowly and vary primarily at business-cycle frequencies (Harvey 1989; Cochrane and Piazzesi 2005; Lustig, Roussanov, and Verdelhan 2010). Under the assumption that risk premia are slow moving, they will be largely differenced out in the high-frequency analysis that follows. To the extent that one is willing to entertain this assumption, the results about the behavior of inflation compensation can also be taken as evidence about inflation expectations.

2.1 Measures of Inflation Compensation

This paper uses two sources of information about inflation compensation: spreads in yields on nominal and inflation-indexed bonds, and inflation swap rates. Absent market frictions and liquidity risk premia, the two measures should coincide. In practice, there are notable discrepancies between the two, so it is worthwhile to include both in any empirical analysis of inflation compensation.[4]

[4]Studies that have compared these measures and investigated reasons for discrepancies include Fleckenstein, Longstaff, and Lustig (2010) and Christensen and Gillan (2011).

2.1.1 TIPS Break-Even Inflation Rates

Treasury Inflation-Protected Securities (TIPS) are bonds that deliver payoffs indexed to the CPI; therefore, yields correspond to real interest rates. The break-even inflation (BEI) rate is the difference between a nominal Treasury yield and the corresponding TIPS yield of the same maturity. This is the rate of inflation that makes investments in indexed and non-indexed bonds equally profitable.

Data on nominal and TIPS zero-coupon yields is readily available. For nominal yields I use the data constructed by Gürkaynak, Sack, and Wright (2007). Zero-coupon TIPS yields are constructed by Gürkaynak, Sack, and Wright (2010). Both data sets are available for download on the Board of Governor's website. Due to low liquidity and indexation effects, TIPS yields at very short maturities are erratic and unreliable; hence, the shortest maturity in the data of Gürkaynak, Sack, and Wright (2010) is two years. The sample period for BEI rates used here starts in January 2, 2003, after the TIPS market had left its infancy. The data sample ends on December 31, 2013.

Generally BEI rates are not equal to inflation compensation, because they contain a liquidity risk premium which captures the differences in liquidity between the nominal Treasury and TIPS market. The effects of this liquidity premium were particularly obvious during the recent financial crisis: during 2008, flight-to-safety effects in the non-indexed Treasury market artificially compressed the spread between nominal and real yields. For some time, the distortions in BEI rates were so large that there was barely any information content about expected future inflation. There are different ways to adjust BEI rates for liquidity premia, including model-based approaches (for example, D'Amico, Kim, and Wei 2010) and straightforward regression-based methods (as in Gürkaynak, Sack, and Wright 2010). In the analysis below, I will report results for observed, unadjusted BEI rates. In addition, I will use liquidity-adjusted BEI rates together with adjusted inflation swap rates to filter an estimate of inflation compensation in a state-space framework.

2.1.2 Inflation Swap Rates

Inflation swaps are financial contracts in which one party pays a fixed interest rate, the swap rate, and the other party pays the CPI inflation rate on an underlying notional. No payments are exchanged until the settlement date, so that one also speaks of a zero-coupon inflation swap. Studies that use data on inflation swaps include Fleckenstein, Longstaff, and Lustig (2010), Christensen and Gillan (2011), and Haubrich, Pennacchi, and Ritchken (2012).

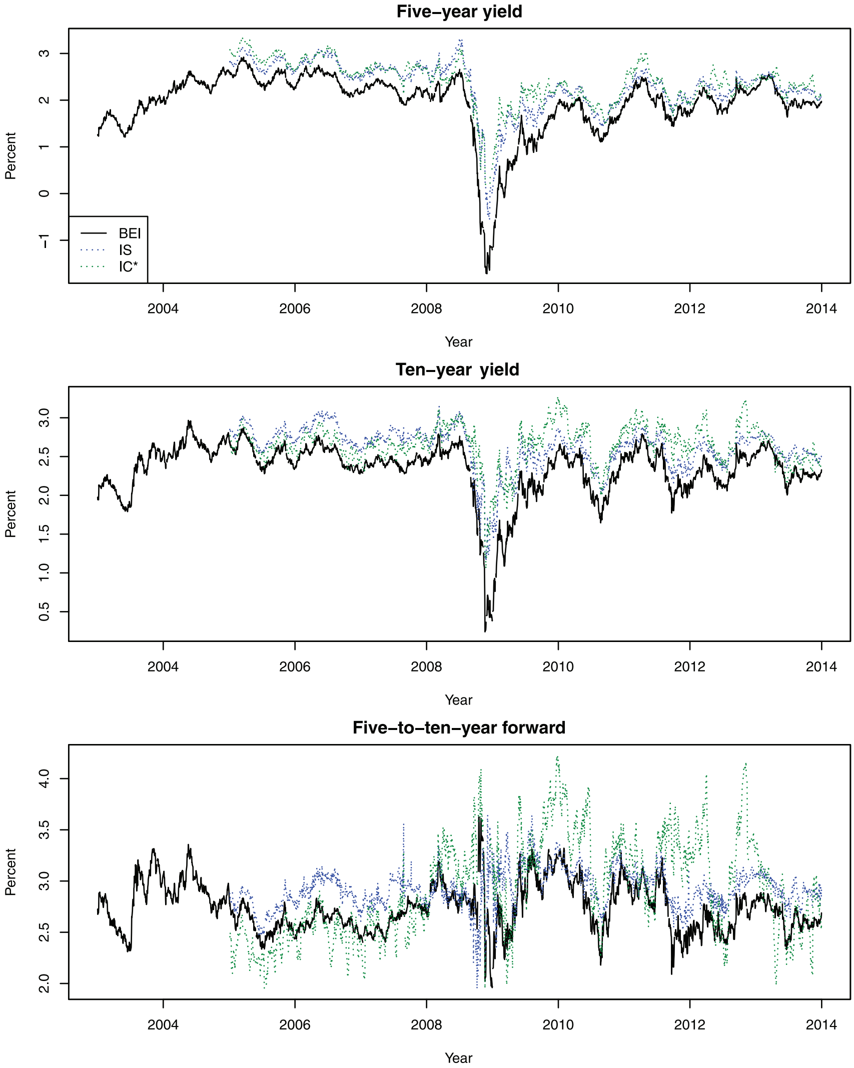
The swap rate data set contains end-of-day rates on U.S. zero-coupon inflation swaps for maturities from one to ten years. The data comes from Bloomberg. Fleming and Sporn (2013) show that these end-of-day quotes are generally very close to actual transaction prices, which is comforting. The sample period is from January 2, 2005, to December 31, 2013.

Empirically, IS rates are typically higher than BEI rates, and this spread was particularly pronounced during the recent financial crisis (see figure 1). The spread arises due to either liquidity premia in TIPS or in IS rates, or a combination of both (Christensen and Gillan 2011). Notably, during the recent financial crisis, inflation swap rates did not show the same anomalous behavior as TIPS break-even spreads. While liquidity premia in different markets often show commonalities (Chordia, Sarkar, and Subrahmanyam 2005), the variability in the BEI-IS spread is an indication that liquidity effects in the swap market differ from those in the TIPS market. Fleckenstein, Longstaff, and Lustig (2010) argue that the spread is largely due to mispricing in the TIPS market, which would be an argument to view IS as a better approximation of the true inflation compensation. Fleming and Sporn (2013) document that the inflation swap market is quite liquid and transparent, with modest bid-ask spreads, which also points to liquidity premia in this market likely being small.

Figure 2 shows rolling correlations of the ten-year BEI rate and the corresponding IS rate. The window length is 250 trading days, corresponding to about one year. For most of the sample period where both series are available, the correlation has been between 0.6 and 0.8. During the crisis period, this correlation dropped to as low as 0.2. This suggests that important market frictions were present during this time, and that the liquidity and risk premia in these two series had important idiosyncratic components.

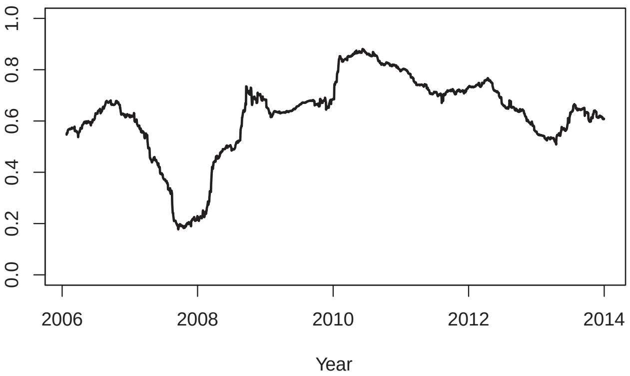
In this paper I do not take a stand on whether BEI or IS rates provide better estimates of the unobserved inflation compensation. I show results for both measures, as well as for a third inflation

Figure 1. Alternative Measures of Inflation Compensation



Notes: The top panel shows alternative measures of inflation compensation for the five-year maturity, the middle panel for the ten-year maturity, and the bottom panel for the five-to-ten-year forward maturity.

Figure 2. Correlation between Ten-Year TIPS Break-Even and Swap Rate



Notes: The figure shows the correlation between daily changes in the TIPS BEI rate and the IS rate for the ten-year maturity, using rolling sub-samples of 250 trading days. The indicated date is the end of the sub-sample window.

compensation measure that combines the available information. Since the results are qualitatively similar across the different measures, we can have some confidence that they are not driven by the behavior of liquidity premia.

2.1.3 Filtering Inflation Compensation from Break-Even and Swap Rates

The two alternative measures of inflation compensation that we have available are presumably both imperfect, due to variation in idiosyncratic factors related to market frictions. Therefore it appears promising to combine the information from both sources, and possibly get an improved estimate of true, unobserved inflation compensation. I will use the following state-space approach to do so:

$$IC_t = IC_{t-1} + w_t \tag{3}$$

$$BEI_t^{adj} = IC_t + v_t^1 \tag{4}$$

$$IS_t^{adj} = IC_t + v_t^2. \tag{5}$$

Equation (3) is the transition equation for the inflation compensation, which is the latent state variable of the state-space system. In the spirit of a local-level model, the transition equation is specified as a random walk. The innovation w_t is taken to be Gaussian and homoskedastic. Equations (4) and (5) are the observation equations, linking break-even inflation and inflation swap rates to inflation compensation. To allow for serially correlated errors, v_t^1 and v_t^2 are specified as autoregressive processes. The (Gaussian) innovations to these processes are allowed to be mutually correlated.

Instead of using observed BEI and IS rates, these measures are first adjusted for liquidity premia. I regress the observed rates on proxies for liquidity risk and take the residual as a premium-adjusted measure, denoted by BEI_t^{adj} and IS_t^{adj}. This is the approach chosen by Gürkaynak, Sack, and Wright (2010), who estimate the liquidity premium in BEI rates using as liquidity proxies the spread between Resolution Funding Corporation strips and Treasury strips, as well as the trading volume in the TIPS market relative to the entire Treasury market. For the BEI rates I use these same proxies. To estimate liquidity premia in IS rates, I use the average bid-ask spreads for inflation swaps of the same maturity (five or ten years).[5] Since this approach identifies only variation in the liquidity premium but not its level, I normalize this to be zero at the end of the sample. To the extent that liquidity premia are not completely purged from BEI^{adj} and IS^{adj}, they will be captured by v_t^1 and v_t^2. It is therefore important to allow for serial correlation in the measurement errors, because liquidity premia are presumably quite persistent. In particular, during the financial crisis period liquidity premia remained persistently high.

To calculate the likelihood function and to filter the latent state variable, I use the Kalman filter. Filtered inflation compensation is obtained for both the five-year and the ten-year maturity. Figure 1 shows all three measures of inflation compensation: observed BEI rates, observed IS rates, and filtered inflation compensation (IC*).

[5]I use twenty-day moving averages of these bid-ask spreads.

2.2 Correlation of Inflation Compensation with Nominal Rates

A natural first step is to calculate unconditional correlations between changes in nominal rates and changes in inflation compensation. Given the decomposition in equation (1), a high correlation implies that variation in inflation compensation is an important source for variation in nominal rates. If, on the other hand, the correlation is low, this would imply that movements in real rates are a more important source of nominal rate volatility.

Table 1 reports correlations of the three different measures of inflation compensation with nominal rates, for the five-year yield, the ten-year yield, and the five-to-ten-year forward rate. The sample starts in January 2005 and ends in December 2013, a period over which observations for both BEI and IS rates are available.

The first row shows correlations for the sample including all daily changes within the sample period. The correlations with nominal rates are quite substantially high for all three measures, particularly at the long end of the yield curve. The correlation is strongest for BEI rates. Overall, it seems that there is an important association between nominal rates and inflation compensation.

The second and third rows show results for the sample that only includes days on which an employment report or CPI numbers were released. On days with employment reports, nominal interest rates typically display a high level of volatility (Bauer 2014). The correlations are particularly high for this sub-sample, which shows that the co-movement of inflation compensation and nominal rates is stronger when the source of volatility is news in the employment report. For days with a CPI release, the estimated correlations between forward inflation compensation and forward rates are also higher than for the whole sample. The volatility in long-term nominal rates caused by news about inflation appears to be associated quite strongly with movements in inflation compensation.

The table also reports correlations for changes at lower sample frequencies, namely, weekly, monthly, and quarterly changes. These correlations are typically larger than the correlations at the daily frequency. Evidently, the relationship between changes in nominal rates and inflation compensation is even stronger at these lower frequencies. However, movements in risk premia, which arguably become

Table 1. Correlations of Inflation Compensation with Nominal Rates

	Five-Year Yield			Ten-Year Yield			Five-to-Ten-Year Forward Rate			
Sample	**BEI**	**IS**	**IC***	**BEI**	**IS**	**IC***	**BEI**	**IS**	**IC***	***N***
Daily, All	0.41	0.27	0.26	0.53	0.31	0.41	0.58	0.17	0.36	2117
Daily, Empl.	0.49	0.32	0.48	0.62	0.40	0.48	0.70	0.24	0.38	105
Daily, CPI	0.28	0.11	0.22	0.50	0.28	0.44	0.66	0.34	0.48	105
Weekly	0.33	0.29	0.24	0.49	0.37	0.39	0.60	0.26	0.40	435
Monthly	0.37	0.39	0.26	0.51	0.36	0.42	0.74	0.30	0.40	98
Quarterly	0.67	0.68	0.70	0.77	0.71	0.76	0.90	0.39	0.49	32

Notes: The table shows unconditional correlations between rate changes in nominal rates and changes in break-even inflation for different samples. BEI is the TIPS break-even rate. IS is the inflation swap rate. IC* is the filtered inflation compensation using information in liquidity-adjusted BEI and IS rates. Results are shown for the ten-year yield, the five-year yield, and the five-by-five-year forward rate. The last column indicates the number of observations used to calculate the correlation coefficient. The first row shows correlations for the sample including all daily changes. The second and third rows show results for the sample that only includes days on which an employment report or CPI numbers were released. Rows 4–6 consider lower sample frequencies, using weekly, monthly, and quarterly changes, respectively. The sample starts on January 3, 2005, and ends on December 31, 2013.

more relevant at lower frequencies, may partly explain this close co-movement.

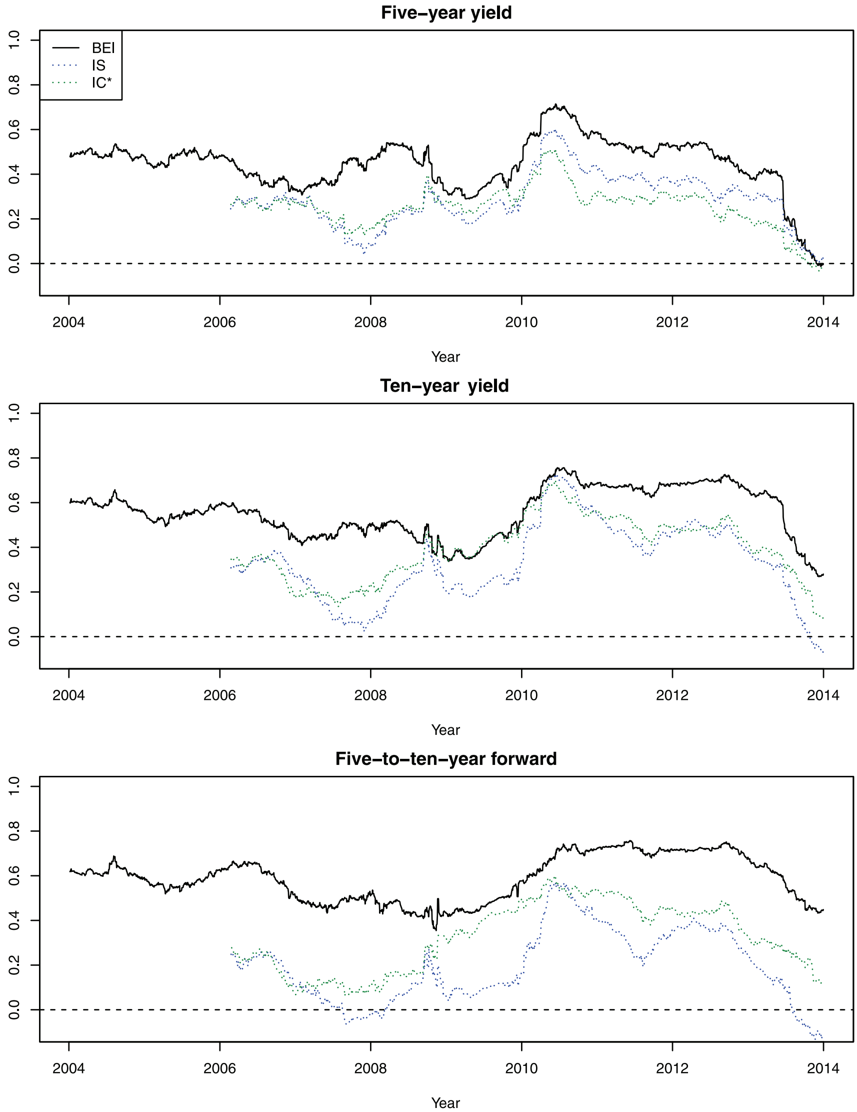
The evidence in table 1 suggests an important role for inflation compensation for explaining volatility in nominal rates. The correlations are sizable and also significantly different from zero in all but one of the cases.[6] While correlations for inflation swaps are somewhat weaker in some cases, overall the finding is robust across the three different measures of inflation compensation. Therefore it seems unlikely that liquidity effects in particular markets contribute a lot to these high correlations. And under the assumption that inflation risk premia are slow moving, the evidence based on daily changes suggests that changes in inflation expectations are correlated with nominal rate changes.

To assess the sub-sample stability of the results above, it is useful to consider how correlations of daily changes in nominal rates and IC have evolved over the sample period. Figure 3 shows rolling correlations for sub-samples of 250 observations, that is, over about one year. The correlation series are shown for all three inflation compensation measures and for three different maturities.

Rolling-sample correlations between inflation compensation and nominal rates exhibit some variation over time. During the financial crisis, correlations were generally lower than at most other times in the sample. For instance, early on in the crisis, IS rates were essentially uncorrelated with nominal rates. The correlations of both IS rates and filtered inflation compensation with nominal rates have generally been lower and more variable than for the BEI rates. After the end of the crisis until about 2012, correlations were high and remained relatively stable, particularly for BEI rates for ten-year yields and five-to-ten-year forward rates. Toward the end of the sample, correlations decrease significantly. For most series in figure 3, the correlations drop to zero by the end of 2013. This may have been a result of the introduction of an explicit inflation target of 2 percent by the Federal Reserve in January 2012. This policy had the goal of more firmly anchoring long-term inflation expectations. As a result,

[6] I carried out significance tests based on the usual Student-t approximation for the correlation coefficient. The p-values, which are not shown, are much smaller than 5 percent in all cases, with the exception of the five-year inflation swap rate over the CPI sub-sample.

Figure 3. Correlations between Inflation Compensation and Nominal Rates



Notes: The figure shows the correlation between daily changes in inflation compensation and nominal rates, using rolling sub-samples of 250 trading days. The indicated date is the end of the sub-sample window. The top panel shows correlations for the five-year maturity, the middle panel for the ten-year maturity, and the bottom panel for the five-to-ten-year forward maturity.

inflation compensation may have become more stable, relative to real rates, which would have decreased the correlation between inflation compensation and nominal rates.

The overall picture that emerges from this evidence is that for the sample as a whole, changes in nominal rates are quite closely associated with changes in inflation compensation. The strength of the co-movement has varied to some degree over time and differs slightly depending on which measure of inflation compensation is used. Overall, however, there appears to have been a significant and rather close relationship for most of the sample period. This suggests that the variation in inflation compensation is an important source for variation in nominal rates.

2.3 Sensitivity of Inflation Compensation to Macroeconomic News

While unconditional correlations are informative about the relationship between nominal rates and inflation compensation, they could be driven by many factors such as changes in liquidity and inflation risk premia, safe-haven demand flows, and others. It is preferable to study movements in asset prices that are caused by fundamental news to agents' perceptions of the current economic situation. To this end, a large literature has focused on the sensitivity of asset prices to macroeconomic data surprises. In what follows, I investigate the sensitivity of inflation compensation to macro news and assess how much it contributes to explaining the sensitivity of nominal rates.

The effects of macroeconomic announcements on asset prices can be estimated using an event study, where changes in asset prices around the time of a data release are regressed on a measure of the surprise component in this release (see, e.g., Balduzzi, Elton, and Green 2001):

$$\Delta p_t = \beta' s_t + \varepsilon_t, \qquad (6)$$

where t indexes days with announcements, Δp_t is the change in an asset price or interest rate around the announcement, and s_t is a $k \times 1$ vector containing the surprise component for each of the k announcements—the kth element of s_t is zero if there was no release for this announcement on day t. Multivariate regression is used in order to partial out the effects of different announcements that occur on the same day. The surprise component is calculated as the difference between the released number and the consensus expectation for the release. This surprise is standardized to have unit variance for the sake of comparability of different releases. The releases I consider are the thirteen data releases that BW include in their analysis. The dependent variables are changes, in basis points, in nominal rates, real rates, and inflation compensation. Hence each element of β has the interpretation of representing the basis-point response of an interest rate to a one-standard-deviation surprise in the corresponding announcement. As in BW, I report results for the five-year yield, the ten-year yield, and the five-to-ten-year forward rate.

Table 2 shows the estimated responses for the TIPS data. The sample period is chosen to exclude the financial crisis, and extends from January 2, 2003, to July 31, 2007. The results show that both real rates and inflation compensation are very sensitive to macroeconomic news. The regression R^2 is quite similar, the surprises are highly jointly significant in both cases, and there are about as many significant coefficients for real rates as there are for inflation compensation. This holds for yields as well as forward rates.

For news about the price level—core CPI, core PPI, and employment cost index (ECI)—the responsiveness is concentrated in BEI rates, consistent with the findings of BW. For real-side macroeconomic news, the results here show that in most cases both real rates and BEI rates contribute significantly to the response of nominal rates. This is true for yields as well as for far-ahead forward rates. This contrasts with the conclusion of BW, who find almost no response of far-ahead forward rates to real-side news, whereas I find that real-side news matters for far-ahead forward inflation compensation. In the specific case of payroll news, the most important economic data release, the sensitivity of forward inflation compensation is highly significant and only slightly smaller than the sensitivity of real forward rates. A few other real-side data releases also significantly affect far-ahead forward inflation compensation.

Table 3 presents the same results for the inflation swap data set, based on a sample period from January 2, 2005, to December 31, 2013. For this later sample, which includes the financial crisis, the nominal rate responses look quite different than for the TIPS BEI sample. R^2 is much smaller, and so are several of the response coefficients, including the one for payroll news. Regarding the relative

Table 2. Market Responses to Macroeconomic News—TIPS

	Ten-Year Yield			Five-Year Yield			Five-by-Five-Year Forward Rate		
	Nominal	**Real**	**IC**	**Nominal**	**Real**	**IC**	**Nominal**	**Real**	**IC**
Capacity	0.12	0.24	−0.11	0.07	0.33	−0.26	0.20	0.14	0.06
	(0.47)	(0.39)	(0.30)	(0.54)	(0.47)	(0.38)	(0.45)	(0.40)	(0.31)
Confidence	0.47	0.11	0.36	0.62	0.37	0.25	0.33	−0.15	0.47
	(0.78)	(0.72)	(0.24)	(0.81)	(0.76)	(0.26)	(0.80)	(0.72)	(0.30)
Core CPI	1.29**	−0.42	1.71***	1.73**	−0.88	2.61***	0.82	0.06	0.76*
	(0.64)	(0.61)	(0.41)	(0.73)	(0.69)	(0.48)	(0.62)	(0.61)	(0.42)
Durable Goods	0.99	1.03	−0.04	1.33	1.68**	−0.35	0.64	0.37	0.27
	(0.77)	(0.68)	(0.37)	(0.93)	(0.82)	(0.49)	(0.63)	(0.58)	(0.31)
ECI	0.04	1.02	−0.98**	−0.03	0.89	−0.93**	0.09	1.15	−1.06*
	(1.21)	(1.04)	(0.46)	(1.19)	(1.24)	(0.42)	(1.33)	(0.92)	(0.63)
Real GDP Adv.	1.77	1.15	0.62	1.50	1.76	−0.26	2.05	0.53	1.52**
	(1.47)	(1.20)	(0.45)	(1.30)	(1.29)	(0.48)	(1.73)	(1.18)	(0.77)
Initial Claims	−1.02***	−0.70***	−0.31**	−1.17***	−0.77***	−0.40**	−0.87***	−0.64**	−0.23
	(0.31)	(0.25)	(0.16)	(0.31)	(0.27)	(0.18)	(0.33)	(0.27)	(0.19)
NAPM	1.74***	1.85***	−0.11	2.06***	2.17***	−0.11	1.36***	1.55***	−0.19
	(0.48)	(0.37)	(0.44)	(0.59)	(0.47)	(0.54)	(0.52)	(0.43)	(0.41)
Non-Farm	5.61***	3.85***	1.76***	6.91***	5.22***	1.70***	4.27***	2.46***	1.81***
Payrolls	(1.46)	(1.05)	(0.46)	(1.78)	(1.34)	(0.50)	(1.16)	(0.81)	(0.47)
New Home	1.13**	0.59	0.54*	1.21*	0.96*	0.25	1.06**	0.23	0.83***
Sales	(0.57)	(0.47)	(0.31)	(0.64)	(0.57)	(0.38)	(0.54)	(0.45)	(0.29)
Core PPI	1.18**	0.19	0.99**	0.92	−0.21	1.13*	1.47***	0.60*	0.87**
	(0.51)	(0.44)	(0.42)	(0.61)	(0.62)	(0.60)	(0.49)	(0.36)	(0.41)
Retail Sales	1.12	1.31**	−0.19	1.35	1.40*	−0.05	0.90	1.22**	−0.32
	(0.92)	(0.66)	(0.36)	(1.00)	(0.84)	(0.34)	(0.89)	(0.53)	(0.49)
Unemployment	−0.50	−0.06	−0.44	−0.91	−0.54	−0.37	−0.07	0.44	−0.52
	(1.05)	(0.77)	(0.38)	(1.20)	(0.91)	(0.37)	(0.97)	(0.77)	(0.48)
R^2	0.148	0.118	0.105	0.174	0.146	0.116	0.103	0.070	0.067
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: The table shows responses to one-standard-deviation surprises in macroeconomic data releases of nominal rates, TIPS-based real rates, and BEI rates, for five- and ten-year yields and the five-by-five-year forward rate. White standard errors are shown in parentheses. p-values are for the hypothesis that all coefficients are jointly zero. Sample: Days with TIPS BEI rates from January 2, 2003, to July 31, 2007.

Table 3. Market Responses to Macroeconomic News—Inflation Swaps

	Ten-Year Yield			Five-Year Yield			Five-by-Five-Year Forward Rate		
	Nominal	Real	IC	Nominal	Real	IC	Nominal	Real	IC
Capacity	0.51	0.02	0.49	1.43	1.28*	0.15	−0.39	−1.22	0.83
	(0.82)	(0.63)	(0.80)	(0.96)	(0.73)	(1.08)	(0.80)	(0.85)	(0.81)
Confidence	0.59	1.22*	−0.63	0.37	1.99***	−1.62	0.79	0.42	0.37
	(0.76)	(0.69)	(0.81)	(0.69)	(0.72)	(1.02)	(0.89)	(1.14)	(1.00)
Core CPI	0.07	−1.80**	1.86*	0.04	−1.79**	1.83**	0.08	−1.81	1.89
	(0.87)	(0.88)	(0.98)	(0.82)	(0.87)	(0.80)	(1.01)	(1.15)	(1.33)
Durable Goods	0.68	0.48	0.19	0.74	1.45**	−0.71	0.62	−0.47	1.10
	(0.56)	(0.44)	(0.39)	(0.61)	(0.69)	(0.76)	(0.59)	(0.84)	(0.68)
ECI	0.35	1.57	−1.23	−0.07	0.80	−0.87	0.76	2.35	−1.58
	(1.06)	(1.23)	(0.78)	(1.08)	(1.29)	(0.77)	(1.14)	(1.58)	(1.17)
Real GDP Adv.	−1.67	0.15	−1.81**	−0.67	1.64	−2.31*	−2.65*	−1.34	−1.31
	(1.16)	(1.07)	(0.82)	(0.98)	(1.12)	(1.23)	(1.38)	(1.94)	(1.46)
Initial Claims	−1.43***	−0.62	−0.81***	−1.51***	−1.03***	−0.47	−1.37***	−0.23	−1.15**
	(0.34)	(0.39)	(0.28)	(0.32)	(0.37)	(0.38)	(0.40)	(0.67)	(0.48)
NAPM	2.41***	1.70***	0.71*	2.13***	0.10	2.03***	2.67***	3.29***	−0.61
	(0.59)	(0.60)	(0.39)	(0.55)	(0.75)	(0.62)	(0.75)	(0.77)	(0.66)
Non-Farm	2.79***	1.37	1.42**	2.89**	1.11	1.78*	2.71**	1.64	1.06*
Payrolls	(1.01)	(1.27)	(0.57)	(1.21)	(1.82)	(0.96)	(1.08)	(1.09)	(0.56)
New Home	0.80*	0.76	0.04	0.77	0.96	−0.19	0.84*	0.56	0.28
Sales	(0.44)	(0.49)	(0.34)	(0.48)	(0.59)	(0.55)	(0.45)	(0.61)	(0.42)
Core PPI	1.83***	0.74**	1.09***	1.46***	0.12	1.35***	2.20***	1.37**	0.83*
	(0.52)	(0.38)	(0.37)	(0.50)	(0.43)	(0.46)	(0.64)	(0.64)	(0.49)
Retail Sales	2.28***	1.60***	0.68	2.03***	0.23	1.80***	2.54***	2.98***	−0.44
	(0.64)	(0.62)	(0.44)	(0.58)	(0.70)	(0.70)	(0.77)	(1.08)	(0.74)
Unemployment	−0.88	−0.96	0.08	−0.98	−1.68**	0.70	−0.79	−0.25	−0.54
	(0.69)	(0.67)	(0.48)	(0.73)	(0.68)	(0.62)	(0.78)	(0.95)	(0.60)
R^2	0.071	0.037	0.059	0.073	0.039	0.061	0.059	0.036	0.031
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001

Notes: The table shows responses to one-standard-deviation surprises in macroeconomic data releases of nominal rates, swaps-based real rates, and inflation compensation (IC) based on inflation swap rates, for five- and ten-year yields and the five-by-five-year forward rate. White standard errors are shown in parentheses. p-values are for the hypothesis that all coefficients are jointly zero. Sample: Days with inflation swap rates from January 2, 2005, to December 31, 2013.

contribution of real rates and inflation compensation to the sensitivity of nominal rates, however, the same results hold. The sensitivity of IS rates is about as high as or, in the case of yields, higher than for real rates, as indicated by R^2. For price-level news, IS rates account for most of the nominal rate response. For the real-side news, both real rates and inflation compensation show significant responses. Inflation compensation is sensitive to employment news, which contributes importantly to the sensitivity of nominal rates.

Table 4 reports results for a decomposition of nominal rates based on filtered inflation compensation, using the same sample period as for inflation swaps.[7] The sensitivity of filtered inflation compensation to macro news is similar to the sensitivity of real rates, as measured by R^2. Responses to price-level news are significant for the five- and ten-year inflation compensation. Forward inflation compensation responds particularly strongly to employment news, where forward real rates do not show a significant response.

The evidence across all three measures of inflation compensation is consistent in that it suggests a high sensitivity of inflation compensation to macroeconomic news, comparable to the response of real rates. Inflation compensation is sensitive to both price-level news and real-side news, and, like nominal rate and real rates, typically responds in a procyclical manner. The sensitivity is evident for both long-term yields and far-ahead forward rates. This is an important component for explaining the strong responses of nominal interest rates to macroeconomic news.

2.4 The Evidence of Beechey and Wright (2009)

While these results are in line with the evidence in Gürkaynak, Levin, and Swanson (2010), they contrast with the conclusions of BW. Based on their analysis of daily and intradaily response of nominal, TIPS, and BEI rates to macro news, they conclude that the response of nominal rates to real-side economic data surprises is concentrated almost exclusively in real rates, and that inflation compensation does not contribute noticeably to the sensitivity of nominal rates. Here I investigate the reasons for the differences in

[7]The sample only includes days with observations on both inflation swap rates and TIPS break-even inflation rates, and so is not identical to the sample used for table 2.

Table 4. Market Responses to Macroeconomic News—Filtered Inflation Compensation

	Ten-Year Yield			Five-Year Yield			Five-by-Five-Year Forward Rate		
	Nominal	**Real**	**IC**	**Nominal**	**Real**	**IC**	**Nominal**	**Real**	**IC**
Capacity	0.49	0.26	0.23	1.42	1.09*	0.33	−0.42	−0.56	0.14
	(0.82)	(0.48)	(0.96)	(0.97)	(0.65)	(0.97)	(0.80)	(0.81)	(1.18)
Confidence	0.87	0.63	0.24	0.66	1.46**	−0.80	1.07	−0.20	1.27
	(0.72)	(0.64)	(0.83)	(0.64)	(0.61)	(0.69)	(0.86)	(0.96)	(1.17)
Core CPI	−0.07	−1.35*	1.27	−0.09	−1.74**	1.65**	−0.07	−0.96	0.89
	(0.87)	(0.76)	(0.99)	(0.82)	(0.74)	(0.67)	(1.02)	(1.07)	(1.46)
Durable Goods	0.54	0.31	0.23	0.65	1.15*	−0.50	0.43	−0.54	0.97
	(0.55)	(0.55)	(0.49)	(0.62)	(0.60)	(0.62)	(0.56)	(0.99)	(0.88)
ECI	0.34	1.52	−1.18**	−0.07	0.23	−0.30	0.75	2.80	−2.05
	(1.06)	(1.18)	(0.60)	(1.08)	(1.23)	(0.61)	(1.14)	(1.71)	(1.26)
Real GDP Adv.	−1.67	−0.90	−0.77	−0.67	1.20	−1.87*	−2.66*	−2.98	0.33
	(1.16)	(1.43)	(1.01)	(0.98)	(1.01)	(1.04)	(1.38)	(3.03)	(2.57)
Initial Claims	−1.47***	−0.64	−0.84**	−1.51***	−1.32***	−0.19	−1.45***	0.04	−1.49***
	(0.34)	(0.40)	(0.34)	(0.33)	(0.32)	(0.29)	(0.41)	(0.67)	(0.57)
NAPM	2.26***	1.16**	1.10*	1.99***	0.31	1.68***	2.52***	2.00**	0.52
	(0.56)	(0.57)	(0.57)	(0.52)	(0.70)	(0.56)	(0.73)	(0.80)	(0.97)
Non-Farm	3.72***	2.22***	1.49***	3.99***	3.58***	0.41	3.46***	0.88	2.58***
Payrolls	(0.68)	(0.63)	(0.50)	(0.79)	(0.59)	(0.55)	(0.98)	(1.01)	(0.76)
New Home	0.76*	0.61	0.15	0.73	0.73	0.00	0.79*	0.49	0.30
Sales	(0.44)	(0.44)	(0.34)	(0.48)	(0.53)	(0.37)	(0.45)	(0.55)	(0.54)
Core PPI	1.83***	0.94**	0.89*	1.47***	0.64	0.83**	2.20***	1.26*	0.95
	(0.52)	(0.47)	(0.54)	(0.50)	(0.45)	(0.38)	(0.64)	(0.75)	(0.85)
Retail Sales	2.27***	1.82***	0.46	2.03***	0.85	1.18*	2.53***	2.80***	−0.26
	(0.64)	(0.59)	(0.44)	(0.58)	(0.62)	(0.62)	(0.77)	(0.99)	(0.71)
Unemployment	−0.91	−0.86	−0.06	−1.02	−1.49**	0.47	−0.81	−0.22	−0.58
	(0.71)	(0.62)	(0.44)	(0.74)	(0.70)	(0.44)	(0.79)	(0.80)	(0.66)
R^2	0.083	0.037	0.032	0.088	0.068	0.046	0.067	0.022	0.024
p-value	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.041	0.020

Notes: The table shows responses to one-standard-deviation surprises in macroeconomic data releases of nominal rates, real rates, and filtered inflation compensation (IC), for five- and ten-year yields and the five-by-five-year forward rate. White standard errors are shown in parentheses. p-values are for the hypothesis that all coefficients are jointly zero. Sample: Days with observations on both inflation swap rates and TIPS break-even inflation rates, January 2, 2005, to December 31, 2013.

results. There are three main factors that can possibly explain the differences in results: (i) the different sample periods, (ii) the use of smoothed vs. unsmoothed yields, and (iii) the length of the sampling windows around the announcements (daily vs. intradaily). I will discuss each of these in turn.

The first difference that drives a wedge between the TIPS results in my table 2 and the results in BW is the sample period. BW include part of the financial crisis period in their data, which lowers the response of break-even inflation to macro news. I have carried out my analysis for the exact same sample period as in BW and generally find smaller sensitivities of inflation compensation, due to the inclusion of the financial crisis period. TIPS spreads have behaved abnormally during the crisis, due to significant flight-to-safety pressures on prices of non-indexed Treasury securities prices. The liquidity premium in the TIPS market increased markedly during the crisis period (Lehnert, Andonov, and Bardong 2009; Christensen and Gillan 2011). I argue that using a sample period that ends before the onset of the crisis, as I do here, gives a cleaner picture of the response of inflation compensation to macroeconomic data surprises.

The second difference is that BW use unsmoothed yields, that is, yields based on quoted prices of nominal and indexed Treasury securities, whereas I use the smoothed nominal and real term structures from Gürkaynak, Sack, and Wright (2007, 2010). The differences in results for smoothed vs. unsmoothed yields are small, as shown by BW in their online appendix, but the sensitivity of inflation compensation to real-side news is slightly larger when using the smoothed data sample. One might argue that smoothing through the idiosyncracies of movements in individual securities promises to give more reliable estimates of shifts in the nominal and real yield curves.

The third and main difference is that I focus on regressions using daily changes, whereas BW also use intradaily changes over thirty-minute windows around announcements. While in their intraday results inflation compensation is largely insensitive to real-side news, the responses are slightly larger and in some cases significant in their daily results. It is worthwhile investigating more carefully the difference between daily and intradaily sensitivities.[8]

---

[8]I thank Meredith Beechey and Jonathan Wright for providing me with their intraday TIPS data.

Table 5 shows estimated sensitivities payroll surprises for nominal rates, real (TIPS) rates, and BEI rates, for the same maturities as before. The sample corresponds to the one used in BW, the only difference being that it only includes days with an employment report. The table shows the sensitivities when using a thirty-minute interval around the announcement, as in BW, and the results are comparable to the ones in BW's table 3.[9] The table also shows sensitivities for longer intraday windows, spanning four hours, and for daily windows (as in BW's table 4). For far-ahead forward rates, which BW focus on, the sensitivity of inflation compensation is insignificant when using a short intradaily window, and becomes larger and significant when using longer sampling windows.

This difference warrants closer investigation of the adjustment over the course of the day. Figure 4 shows the response of the nominal forward rate (top row), the real forward rate (middle row), and the forward inflation compensation (bottom row) for different intradaily windows. The left panel shows the response coefficients and 95 percent confidence intervals for windows that start fifteen minutes before the release and end fifteen minutes to four hours after the release, that is, cumulative responses (similar to BW's figures 2 and 3). The right panel shows estimates of the responses (with 95 percent confidence intervals) for non-overlapping windows: the first error bar is for the thirty-minute window around the release; the following ones are for the subsequent fifteen-minute windows. While at first sight the top-left and middle-left panels seem to indicate that all new information is incorporated immediately into nominal and real rates and no further adjustments occur after the first thirty minutes (the conclusion of BW), this is not the whole story. The top panels in fact show that the nominal forward rate exhibits a small but significant response in the two following fifteen-minute intervals. This is not the case for the real forward rate (middle panels), and thus this delayed response occurs in the forward inflation compensation, as is evident in the bottom panels: The forward inflation compensation does not respond at all during the thirty-minute window around the announcement, but over the subsequent periods adjusts upward.

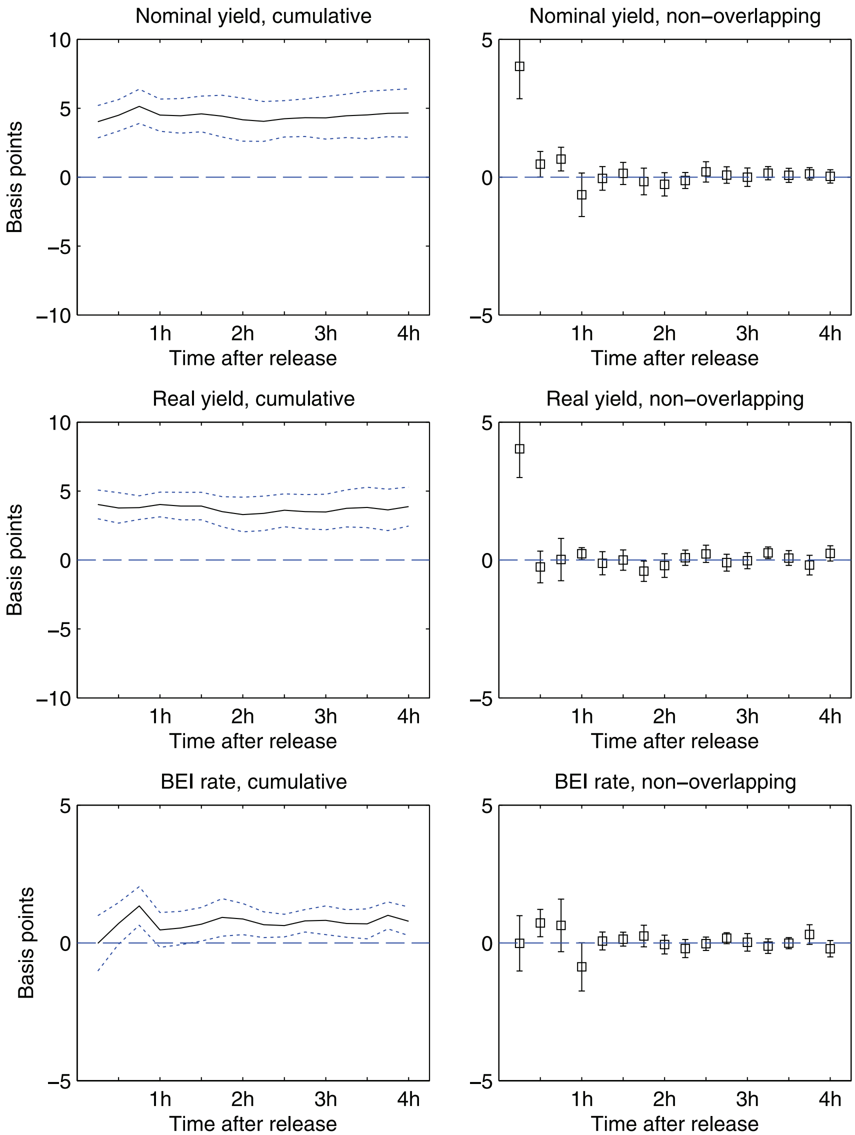
[9]The magnitude of the coefficients also differs from the ones in BW because the standard deviations that they use to standardize differ from mine, for an unknown reason. This, however, does not affect the relative contribution of real and break-even rates in explaining the nominal rate response.

Table 5. Intradaily and Daily Responses to Non-Farm Payroll Surprise

Ten-Year Yield			Five-Year Yield			Five-by-Five-Year Forward Rate		
Nominal	**Real**	**IC**	**Nominal**	**Real**	**IC**	**Nominal**	**Real**	**IC**
Thirty-Minute Window								
6.61	5.18	1.43	8.58	6.27	2.31	4.02	4.03	−0.01
(0.63)	(0.46)	(0.33)	(0.79)	(0.66)	(0.42)	(0.58)	(0.52)	(0.50)
Four-Hour Window								
6.55	4.95	1.59	7.99	6.05	1.94	4.65	3.87	0.79
(0.91)	(0.78)	(0.24)	(1.00)	(0.92)	(0.33)	(0.88)	(0.70)	(0.26)
Daily Window								
6.70	5.03	1.66	8.23	6.25	1.98	4.70	3.76	0.94
(0.92)	(0.80)	(0.29)	(1.02)	(0.93)	(0.37)	(0.86)	(0.78)	(0.28)

Notes: The table shows responses of nominal, real, and break-even inflation (BEI) rates to a one-standard-deviation surprise in non-farm payrolls, using a thirty-minute window around the announcement (8:15 a.m. to 8:45 a.m.), a four-hour window (8:15 a.m. to 12:15 p.m.), and a daily window (4 p.m. previous day to 4 p.m. on the announcement day). White standard errors are in parentheses. The sample includes employment reports from March 2004 to June 2008.

Figure 4. Intraday Responses of Nominal Rates, Real Rates, and IC to Payroll Surprises



Notes: The left panel shows cumulative responses to a one-standard-deviation surprise in non-farm payrolls from 15 minutes before the release until 15 to 240 minutes after the release. The right panel shows responses during non-overlapping windows, the first one spanning 30 minutes around the release and the following each spanning subsequent 15-minute windows. Top row: nominal yield. Middle row: TIPS/real yield. Bottom row: break-even inflation (BEI) rate. Also shown are 95 percent confidence intervals based on White standard errors.

One can only speculate as to the reasons for the delay of this response. It seems that a delayed adjustment should be arbitraged away, since such a predictable pattern would in principle generate a profitable trading opportunity: after observing a positive payroll surprise, a trader could enter into a long five-to-ten-year inflation compensation position, which would on average generate a positive payoff. However, this is not necessarily an arbitrage opportunity for at least two reasons: First, the expected payoff might be too small to warrant the riskiness of such a trade. Second, the expected movement of about 1 basis point could be practically irrelevant given the prevailing bid-ask spreads in Treasury and TIPS markets—Fleming and Remolona (1999) show that after announcements, the spreads in the Treasury market significantly widen. There is evidence that even in highly liquid markets, delayed adjustment of prices to macroeconomic announcements is not always arbitraged away. For example, Taylor (2010) shows that federal funds futures adjust even until two hours after the announcement.

So should we be using tight intradaily windows or daily changes to assess the impact of macro surprises? If the effect of macro news on asset prices is processed quickly, say within minutes, and no more processing takes place over the rest of the day, then "sizeable efficiency gains can be obtained from running these regressions with intradaily data, rather than data at the daily frequency" (Beechey and Wright 2009, p. 536). In this case the daily change is equal to the intradaily change plus noise that is unrelated to the surprise, and tight windows around the announcements are clearly preferable. However, for certain asset prices, the information processing may take longer than several minutes. Estimates based on a tight window may then miss part or all of the announcement effect, whereas estimates using longer windows recover it correctly. In general, it seems desirable to carry out event studies of announcement effects using different window lengths. This ensures that one will pick up the sensitivities to surprises, even if there is a delayed adjustment, as in the case of the response of forward BEI rates to payroll news.

3. Survey-Based Measures of Inflation Expectations

The previous section has shown that at high frequencies, inflation compensation is an important factor driving the volatility of nominal interest rates. The main concern is that this result may be partly driven by movements in the inflation risk premium. This concern can be alleviated by arguing that inflation risk premia likely move primarily at lower frequency, as discussed above. Another important point, made by Gürkaynak, Levin, and Swanson (2010), is that it would be difficult to attribute the procyclical response of inflation compensation to movements in risk premia, because there is ample evidence that risk premia move in a countercyclical fashion. While these arguments suggest that inflation expectations are the driving force between the evidence documented in the previous section, it is desirable to use more direct measures of inflation expectations. To this end, the analysis in this section uses inflation expectations from surveys of professional forecasters. Such survey forecasts have been found by several studies to predict future inflation quite well, and in particular better than model-based or market-based inflation forecasts (Ang, Bekaert, and Wei 2007; Faust and Wright 2013).

3.1 Survey Data

For the analysis of survey expectations of future inflation, I use data from the Blue Chip Economic Indicators survey, as well as from the Survey of Professional Forecasters (SPF). Throughout the analysis in this section, the focus will be on *revisions* to inflation expectations, that is, changes in expectations between two successive survey observations.

3.1.1 Blue Chip Economic Indicators

Blue Chip Economic Indicators has conducted monthly surveys of business economists since 1976, which ask about respondents' price-level expectations for each future quarter up until the end of the year following the survey. The survey includes questions about both the consumer price index (CPI) and the GDP price index (PGDP). I focus on one-year forecasts, the longest available horizon that is available in every survey. The survey responses are collected around the turn of each month, and the results are released in the second week of each month. To line up the survey data with yields and macroeconomic news, I associate the last day of the preceding month with each survey, which closely corresponds to the actual timing of the forecasters' information set.

In March and October of each year, Blue Chip also surveys respondents about their long-term inflation forecasts for the next ten years.[10] I include in the analysis the long-term forecasts of CPI and PGDP over the next five years and over the next ten years.

3.1.2 Survey of Professional Forecasters

The Survey of Professional Forecasters (SPF) has been conducted on a quarterly basis since 1968. Since 1990 it has been managed by the Federal Reserve Bank of Philadelphia. Like the Blue Chip survey, it also targets business and market economists. The survey asks about both short-term and long-term inflation forecasts. One-year-ahead forecasts are available for CPI and PGDP inflation, and ten-year forecasts are available for CPI inflation. The survey results are released early in the middle month of each quarter, and I time the SPF survey data using the last day of the first month of each quarter, a reasonably good approximation for the information set of the respondents.

3.2 Correlation of Survey Expectations with Nominal Interest Rates

As in the case of inflation compensation, I first investigate unconditional correlations with nominal interest rates. Table 6 displays the correlations of changes in nominal Treasury yields with the different survey-based measures of inflation expectations. The yield maturity is matched to the horizon of the inflation forecasts. For example, the five-year yield is used to calculate the correlation with the long-term Blue Chip forecasts of inflation over the next five years. The frequency of the changes is monthly for short-term Blue Chip forecasts, semi-annual[11] for long-term Blue Chip forecasts, and

[10] These long-term forecasts are available back to 1979.

[11] The long-term Blue Chip forecasts are released in March and October, so the changes are over intervals of five and seven months.

Table 6. Correlations of Survey-Based Inflation Expectations with Nominal Rates

		Long Sample		Short Sample			
Survey	**Mat.**	**CPI**	**PGDP**	**CPI**	**PGDP**	**BEI**	**IS**
Blue Chip:							
Short-Term	1y	0.13	0.28	−0.04	0.27	0.34	0.31
		[0.03]	[0.00]	[0.67]	[0.00]	[0.00]	[0.00]
Long-Term	5y	0.28	0.23	0.21	0.25	0.30	0.40
		[0.06]	[0.12]	[0.41]	[0.31]	[0.23]	[0.10]
Long-Term	10y	0.27	0.10	0.21	0.20	0.42	0.39
		[0.07]	[0.48]	[0.41]	[0.42]	[0.08]	[0.11]
SPF:							
Short-Term	1y	0.36	0.33	0.26	0.30	0.20	0.30
		[0.00]	[0.00]	[0.11]	[0.07]	[0.23]	[0.07]
Long-Term	10y	0.16	—	0.17	—	0.13	0.20
		[0.14]	—	[0.33]	—	[0.44]	[0.22]

Notes: The table shows correlations between changes in nominal Treasury yields and survey-based inflation expectations. Changes are monthly for short-term Blue Chip expectations, semi-annual for long-term Blue Chip expectations, and quarterly for SPF expectations. Also shown are correlations with changes in inflation compensation, measured by TIPS break-even inflation (BEI) and inflation swap (IS) rates, over the same intervals. Numbers in squared brackets are p-values based on Student-t approximations. The long sample starts with the first observation in 1990 for Blue Chip and short-term SPF data, and in October 1991 for long-term SPF data. The short sample starts July 2004, when both swap and short-term break-even data becomes available. All samples end with the last survey in 2013.

quarterly for SPF forecasts. In addition to the estimated correlation coefficients, the table shows p-values based on a Student-t approximation.[12]

In the first two columns, table 6 shows correlations between survey expectations and nominal rates over a long sample starting with the first survey in 1990 and ending with the last survey in 2013.[13]

[12]Significance of the estimated correlation coefficient ρ can be tested using $t = \rho/\sqrt{(1-\rho^2)/(n-2)}$, where n is the number of observations, which approximately has a Student-t distribution with $n-2$ degrees of freedom.

[13]The long-term SPF forecasts first become available in 1991.

The correlations are moderately high, typically around 0.30, even for some of the long-term forecasts. The correlation coefficients are strongly significant for the one-year forecast horizon. For the long-term forecasts, only the correlations for Blue Chip CPI forecasts are (marginally) significant.

To put these numbers into perspective, the table also reports correlations of yields with survey expectations for a shorter sample, starting in July 2004, where data on inflation compensation is available. Over this shorter sample, these correlations can be compared with the correlations of nominal yields with inflation compensation, measured by BEI and IS rates. This comparison shows that the association of nominal rates with survey-based inflation expectations is, in most cases, similarly strong as the association with inflation compensation. This is certainly true for the one-year horizon; however, for long-term forecasts the correlation coefficients are estimated to be insignificant over these short samples.

Overall this evidence suggests that even at these lower frequencies, a fair share of the variation in nominal yields, both at short and long maturities, is related to movements in inflation expectations. It therefore appears that the co-movement of inflation compensation and nominal rates is not driven by changes in inflation risk or liquidity premia, but that movements in inflation expectations play an important role. The evidence is stronger at short forecast horizons.

3.3 Sensitivity of Survey Expectations to Macroeconomic News

A key question of this paper is whether macroeconomic data surprises systematically affect inflation expectations. Here, I address it using survey expectations of future inflation. Since surveys are conducted at monthly or lower frequencies, we cannot estimate the response of expectations over tight windows around the news announcements. In addition, economic agents receive a host of new information over the course of the period between surveys, many of which may affect inflation expectations. This makes the sensitivity estimates in the macro news regression imprecise, and works against finding any significant relationships. However, the results below show that, in fact, inflation expectations do show significant responses to macro news.[14]

In the following regressions, the dependent variable is the change in expectations over the month or quarter. The independent variables are the surprise component in each macroeconomic data release, first standardized to have unit variance, and then cumulated over the month or quarter. That is, the data surprises are constructed exactly as before, except for the fact that they are added up over longer intervals.

Table 7 shows the estimated sensitivities of Blue Chip inflation expectations to macro news, together with White standard errors. Also shown are the sensitivities of the one-year nominal yield, using monthly changes as well. These results are based on 288 monthly observations, starting in January 1990 and ending in December 2013.

Blue Chip expectations for PGDP inflation exhibit significant responses to macro news. The response coefficients are strongly jointly significant, with a p-value below 0.1 percent. For six out of the thirteen releases, the response coefficients are significantly different from zero, and they almost all show the expected procyclical responses. The regression R^2 of 12.4 percent is sizable, in light of the wide (monthly) observation intervals. Expectations of CPI inflation are much less sensitive to macro news, and in this case we cannot reject the null hypothesis that all coefficients are jointly zero. A comparison of the results for PGDP inflation expectations with those for nominal yield reveals that, overall, the survey expectations show an almost similarly large response. The R^2 for survey expectations is only slightly smaller than that for the nominal yield. For non-farm payrolls, both yield and survey expectations show a significant response, and the latter accounts for a fraction of about 0.3 of the former. For capacity utilization, the expectations response accounts for about one-half of the yield response.

Table 8 reports the results for the SPF data. It shows responses for one-year inflation expectations for CPI and PGDP, and expectations for ten-year CPI inflation, together with responses of the one-year and ten-year nominal yield. All coefficients measure the response of quarterly changes to the macro news cumulated over

[14]Since the long-term Blue Chip forecasts are only released twice a year, I do not include these data in this analysis.

Table 7. Sensitivity of Blue Chip Inflation Expectations to Macroeconomic News

	Yield	**BC-CPI**	**BC-PGDP**
Capacity	2.39**	0.16	1.23***
	(1.21)	(0.46)	(0.47)
Confidence	4.42***	0.46	0.57
	(1.52)	(0.54)	(0.56)
Core CPI	−0.34	1.00*	0.89*
	(1.23)	(0.52)	(0.51)
Durable Goods	0.51	0.24	0.83*
	(1.40)	(0.53)	(0.48)
ECI	1.70	0.02	1.07*
	(2.79)	(0.89)	(0.64)
Real GDP Adv.	−2.12	−0.37	−1.56**
	(2.04)	(0.84)	(0.77)
Initial Claims	−1.46	−0.26	−0.32
	(0.91)	(0.28)	(0.27)
NAPM	1.88	0.66	−0.09
	(1.48)	(0.49)	(0.48)
Non-Farm Payrolls	5.52***	0.40	1.54***
	(1.27)	(0.43)	(0.39)
New Home Sales	0.59	0.69*	0.47
	(1.22)	(0.40)	(0.52)
Core PPI	−0.68	0.49	0.28
	(1.10)	(0.44)	(0.43)
Retail Sales	3.98***	−0.40	−0.08
	(1.47)	(0.59)	(0.54)
Unemployment	−3.36**	0.71	0.64
	(1.46)	(0.60)	(0.53)
R^2	0.194	0.049	0.124
p-value	0.000	0.359	0.000

Notes: The table shows response coefficients and White standard errors (in parentheses) for changes in the one-year nominal yield and one-year inflation expectations in CPI and PGDP from the Blue Chip Economic Indicators survey. Significance at the 10 percent, 5 percent, and 1 percent levels are denoted by *, **, and ***, respectively. p-values are for the hypothesis that all coefficients are jointly zero. Sample: Monthly observations from January 1990 to December 2013.

Table 8. Sensitivity of SPF Inflation Expectations to Macroeconomic News

	One-Year Yield	One-Year CPI	One-Year PGDP	Ten-Year Yield	Ten-Year CPI
Capacity	5.51**	3.10*	3.02**	0.21	−1.87***
	(2.37)	(1.85)	(1.32)	(2.65)	(0.66)
Confidence	10.51***	3.32***	1.62	6.60**	−0.29
	(3.30)	(1.26)	(1.32)	(2.86)	(0.64)
Core CPI	−1.77	1.61**	0.54	1.53	2.02***
	(2.33)	(0.69)	(0.87)	(2.15)	(0.74)
Durable Goods	−2.93	0.15	0.38	−3.43	−1.26
	(2.86)	(1.26)	(1.31)	(3.41)	(0.89)
ECI	1.78	1.64	4.45**	−1.98	0.09
	(5.24)	(1.62)	(1.84)	(4.89)	(0.97)
Real GDP Adv.	−5.55	−3.38*	−1.06	0.20	0.33
	(3.72)	(1.77)	(1.71)	(4.36)	(0.88)
Initial Claims	−1.51	−0.10	0.42	1.04	0.47
	(1.82)	(0.56)	(0.58)	(1.76)	(0.32)
NAPM	2.49	1.67	2.10	4.11*	1.66***
	(2.44)	(1.65)	(1.34)	(2.12)	(0.56)
Non-Farm Payrolls	9.86***	−1.27	0.41	9.68***	0.25
	(2.66)	(1.47)	(1.68)	(2.62)	(0.68)
New Home Sales	1.84	1.21	1.61	2.01	−0.60
	(3.05)	(0.99)	(1.23)	(2.11)	(0.40)
Core PPI	0.28	2.23**	1.26	−0.70	−1.14*
	(2.25)	(1.06)	(1.13)	(2.75)	(0.58)
Retail Sales	5.14**	0.93	−0.09	8.87***	0.83
	(2.60)	(1.42)	(1.85)	(2.70)	(0.76)
Unemployment	−0.53	−0.86	−0.77	4.26**	−0.65
	(2.04)	(1.16)	(1.15)	(2.15)	(0.69)
R^2	0.379	0.235	0.241	0.324	0.281
p-value	0.000	0.035	0.029	0.001	0.015

Notes: The table shows response coefficients and White standard errors (in parentheses) for changes in nominal yields and in SPF forecasts of future CPI and PGDP inflation. Significance at the 10 percent, 5 percent, and 1 percent levels are denoted by *, **, and ***, respectively. p-values are for the hypothesis that all coefficients are jointly zero. Sample: Quarterly observations from 1990:Q1 to 2013:Q4.

the course of the quarter. The sample period is from 1990:Q1 to 2013:Q4.

Quarterly changes in SPF inflation expectations show a close relationship with macroeconomic data surprises. This holds for both short-term and long-term expectations. For all three expectations measures, the coefficients are jointly significant at the 5 percent level. Several coefficients are strongly significant, and most of these have the expected sign, indicating a procyclical response. While non-farm payroll news does not lead to a significant response of SPF inflation expectations, other real-side news does.[15] The regression R^2 is on the order of 24–28 percent, which comes quite close to the R^2 for the nominal yields.

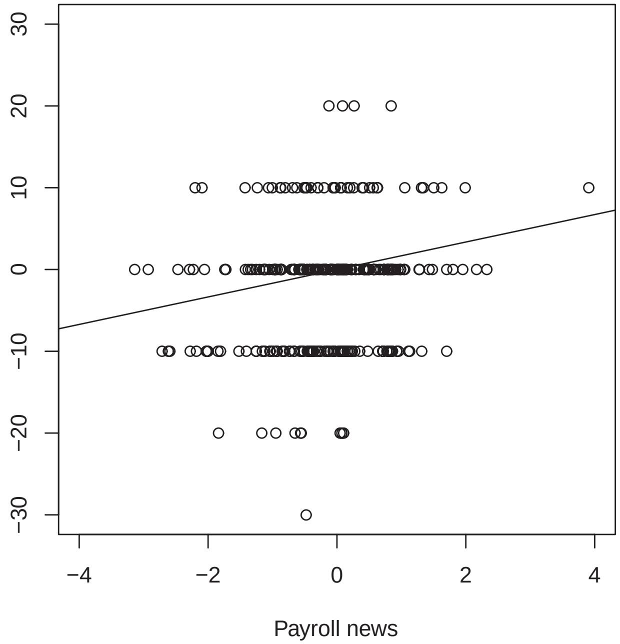
To find a significant relationship between macroeconomic news and changes in inflation expectations over monthly intervals is surprising, given the host of other news that economic agents and forecasters receive which we cannot control for. It is therefore important to investigate the robustness of these results. I have estimated these regressions over different sub-samples, using different timing assumptions, and including different sets of data releases. The results are robust and remain unchanged from my baseline specification.[16] As an example that the results are not driven by a few high-leverage outliers, figure 5 shows a scatter plot of non-farm payroll news against changes in Blue Chip PGDP expectations. In a univariate regression, payroll news is highly significant, as in the multivariate regression, and this significant relationship is evident in the figure. Leaving out the one or two most influential observations does not change this result. I have also studied bivariate relationships in various other cases, and checked the sensitivity to outliers. The sensitivity of survey expectations to macro news is a robust finding.

The overall picture that emerges here is that several survey-based measures of inflation expectations show significant responses

[15] Additional analysis shows that payroll news leads to significant and sizable (about 4 basis points) revisions of one-year SPF inflation expectations with a one-period delay.

[16] The baseline specification uses the same data releases as in section 2 (which are the ones used in BW), employs the full sample of available data, and uses straightforward and plausible timing assumptions, based on the information set of survey respondents when data are collected.

Figure 5. Response of Inflation Expectations to Payroll News



Notes: Monthly changes in Blue Chip PGDP expectations, in basis points, against surprises in non-farm payroll employment. Sample: January 1990 to December 2013. Solid line represents univariate regression equation. $R^2 = 4.1$ percent.

to macroeconomic news. This is true for both price-level and real-side news. The magnitude of the responses to the major price and real-side news differs depending on the survey measure and horizon, but is generally comparable in magnitude to the estimates based on inflation compensation. This suggests that the sensitivity of inflation expectations likely plays an important role in explaining the sensitivity of inflation compensation to macroeconomic news. The evidence is stronger for short-term inflation expectations, but also present for long-term expectations for inflation over a ten-year horizon. Taken together, this evidence supports the view that inflation expectations have been quite variable in the United States and played an important role in explaining movements in nominal interest rates.

4. Conclusion

This paper addresses the question of how important movements in inflation expectations are for explaining variation in nominal interest rates. An analysis of market-based inflation measures documents that estimates of inflation compensation are closely related to movements in nominal rates, and that they are quite sensitive to macroeconomic data surprises. News about the price level as well as news about the real side of the economy, such as surprises in non-farm payroll employment, causes significant responses of inflation compensation. To address the concern that this result might be driven by movements in risk premia or liquidity factors, I also investigate the behavior of survey-based inflation expectations. These are found to display significant responses to macroeconomic news as well.

Taken together, this evidence suggests that inflation expectations change in response to incoming news, and that these responses are an important source of variation for movements in long-term nominal interest rates. A possible explanation for the volatility and sensitivity of inflation expectations, in line with Gürkaynak, Levin, and Swanson (2010) and Beechey, Johanssen, and Levin (2011), is that inflation expectations might not have been very well anchored in the United States. For most of the sample period considered here, U.S. monetary policy did not have an explicit inflation target. Presumably, the introduction of such a target by the Federal Reserve in 2012 would reduce the variability of inflation expectations and hence of long-term nominal interest rates. This additional stability in financial markets would have potentially important economic benefits: More stable long-term interest rates would reduce the uncertainty that investors and, more generally, economic agents face, and in this way would have important positive welfare implications. The Federal Reserve explicitly announced an inflation target in January 2012. Whether this has started to reduce the variability of inflation expectations and consequently of nominal rates is an important question. The decreasing correlations I have reported tentatively suggest that variation in inflation expectations is starting to become less important. However, we do not yet have sufficient data on this new regime to obtain conclusive evidence to answer this question.

References

Ang, A., G. Bekaert, and M. Wei. 2007. "Do Macro Variables, Asset Markets, or Surveys Forecast Inflation Better?" *Journal of Monetary Economics* 54 (4): 1163–1212.

Balduzzi, P., E. J. Elton, and T. C. Green. 2001. "Economic News and Bond Prices: Evidence from the U.S. Treasury Market." *Journal of Financial and Quantitative Analysis* 36 (4): 523–44.

Bauer, M. D. 2014. "Nominal Rates and the News." Forthcoming in *Journal of Money, Credit and Banking.*

Beechey, M. J., B. K. Johannsen, and A. T. Levin. 2011. "Are Long-Run Inflation Expectations Anchored More Firmly in the Euro Area than in the United States?" *American Economic Journal: Macroeconomics* 3 (2): 104–29.

Beechey, M. J., and J. H. Wright. 2009. "The High-Frequency Impact of News on Long-Term Yields and Forward Rates: Is It Real?" *Journal of Monetary Economics* 56 (4): 535–44.

Chordia, T., A. Sarkar, and A. Subrahmanyam. 2005. "An Empirical Analysis of Stock and Bond Market Liquidity." *Review of Financial Studies* 18 (1): 85–129.

Christensen, J. H. E., and J. M. Gillan. 2011. "A Model-Independent Maximum Range for the Liquidity Correction of TIPS Yields." Working Paper No. 2011-16, Federal Reserve Bank of San Francisco.

Christensen, J. H. E., J. A. Lopez, and G. D. Rudebusch. 2010. "Inflation Expectations and Risk Premiums in an Arbitrage-Free Model of Nominal and Real Bond Yields." *Journal of Money, Credit and Banking* 42 (s1): 143–78.

Clarida, R., J. Gali, and M. Gertler. 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory." *Quarterly Journal of Economics* 115 (1): 147–80.

Cochrane, J. H., and M. Piazzesi. 2005. "Bond Risk Premia." *American Economic Review* 95 (1): 138–60.

D'Amico, S., D. H. Kim, and M. Wei. 2010. "Tips from TIPS: The Informational Content of Treasury Inflation-Protected Security Prices." FEDS Paper No. 2010-19, Board of Governors of the Federal Reserve System.

Faust, J., and J. H. Wright. 2013. "Forecasting Inflation." In *Handbook of Economic Forecasting*, Vol. 2, Part A, ed. G. Elliott and A. Timmerman, 2–56 (chapter 1). North-Holland.

Fleckenstein, M., F. A. Longstaff, and H. Lustig. 2010. “Why Does the Treasury Issue Tips? The Tips-Treasury Bond Puzzle.” NBER Working Paper No. 16358.

Fleming, M. J., and E. M. Remolona. 1999. “Price Formation and Liquidity in the U.S. Treasury Market: The Response to Public Information.” *Journal of Finance* 54 (5): 1901–15.

Fleming, M. J., and J. R. Sporn. 2013. “Trading Activity and Price Transparency in the Inflation Swap Market.” *Economic Policy Review* (Federal Reserve Bank of New York) 19 (1): 45–57.

Gürkaynak, R. S., A. T. Levin, and E. T. Swanson. 2010. “Does Inflation Targeting Anchor Long-Run Inflation Expectations? Evidence from the U.S., U.K., and Sweden.” *Journal of the European Economic Association* 8 (6): 1208–42.

Gürkaynak, R. S., B. P. Sack, and E. T. Swanson. 2005. “The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models.” *American Economic Review* 95 (1): 425–36.

Gürkaynak, R. S., B. P. Sack, and J. H. Wright. 2007. “The U.S. Treasury Yield Curve: 1961 to the Present.” *Journal of Monetary Economics* 54 (8): 2291–2304.

———. 2010. “The TIPS Yield Curve and Inflation Compensation.” *American Economic Journal: Macroeconomics* 2 (1): 70–92.

Harvey, C. R. 1989. “Time-Varying Conditional Covariances in Tests of Asset Pricing Models.” *Journal of Financial Economics* 24 (2): 289–317.

Haubrich, J. G., G. Pennacchi, and P. Ritchken. 2012. “Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps.” *Review of Financial Studies* 25 (5): 1588–1629.

Lehnert, T., A. Andonov, and F. Bardong. 2009. “TIPS, Inflation Expectations and the Financial Crisis.” Research Working Paper No. 09-09, Luxembourg School of Finance, University of Luxembourg.

Lustig, H. N., N. L. Roussanov, and A. Verdelhan. 2010. “Countercyclical Currency Risk Premia.” NBER Working Paper No. 16427.

Orphanides, A. 2008. “Taylor Rules.” In *The New Palgrave Dictionary of Economics,* ed. S. N. Durlauf and L. E. Blumeeds. Basingstoke: Palgrave Macmillan.

Taylor, J. B. 1993. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy* 39: 195–214.

———. 1999. "A Historical Analysis of Monetary Policy Rules." In *Monetary Policy Rules*, ed. J. B. Taylor, 319–48. Chicago: University of Chicago Press and NBER.

Taylor, N. 2010. "The Determinants of Future U.S. Monetary Policy: High-Frequency Evidence." *Journal of Money, Credit and Banking* 42 (2–3): 399–420.

Wallace, M. S., and J. T. Warner. 1993. "The Fisher Effect and the Term Structure of Interest Rates: Tests of Cointegration." *Review of Economics and Statistics* 75 (2): 320–24.

Explaining Interest Rate Decisions when the MPC Members Believe in Different Stories*

Carl Andreas Claussen[a] and Øistein Røisland[b]
[a]Sveriges Riksbank
[b]Norges Bank

Most central banks explain interest rate decisions, i.e., they provide a story. With committee decisions, it can be difficult to find a story that is both consistent with the decision and representative for the committee. We consider two alternative procedures: (i) vote on the interest rate and let the winner decide the story, or (ii) vote on the elements of the story and let the interest rate follow from the story. The two procedures tend to result in different outcomes due to an aggregation inconsistency called the discursive dilemma. We find that (ii) tends to yield better stories.

JEL Codes: E52, E58, D71.

1. Introduction

Modern central banks are transparent. One feature of this transparency is that central banks not only announce the interest rate decision, but they also explain *why* they reached this decision. Thus, modern central banks communicate actual monetary policy decisions and the "story" explaining the decisions. However, finding a story that both represents the view of a majority of the monetary policy committee (MPC) and explains the decision is not straightforward. Kohn (2001), who assessed the transparency of the policy-making process at the Bank of England MPC, puts it this way: "To achieve at least rough alignment between policy and the forecast, whatever is published should reflect the 'center of gravity' of the Committee that made itself felt in the most recent policy decision.

*Author contact: Claussen: Sveriges Riksbank, 103 37 Stockholm, Sweden (carl-andreas.claussen@riksbank.se). Roisland: Norges Bank, Box 1179, Sentrum, 0107 Oslo, Norway (oistein.roisland@norges-bank.no).

Table 1. The Discursive Dilemma: An Example

	Story		Interest Rate
	rr_t^*	y_t	r_t
Members 1–3	2.0	1.0	4.5
Members 4–6	2.5	0.0	4.5
Members 7–9	2.0	0.0	4.0
Majority	2.0	0.0	4.5

However, determining and presenting a view that would explain actions and shape expectations constructively is difficult in the context of a Committee, especially one with emphasis on individual accountability."

This paper explores how the "discursive dilemma" can influence the clarity and quality of communication when monetary policy decisions are explained to the public. The discursive dilemma can arise in monetary policy if several policymakers jointly decide on the level of the policy rate based on their views of underlying macroeconomic variables, economic relationships, and preferences, i.e., the "premises" for the decision. If the median view of the policy rate deviates from the policy rate that is implied by the median view of the premises, there is a discursive dilemma. The following example gives an illustration of the dilemma and how it influences the clarity with which monetary policy decisions can be explained to the public.

Suppose that the MPC members' reaction functions are represented by the Taylor rule

$$r_t = rr_t^* + \pi^* + 1.5(\pi_t - \pi^*) + 0.5y_t, \tag{1}$$

where r_t is the nominal interest rate (the decision variable), rr_t^* is the neutral real interest rate, π^* is the desired rate of inflation (inflation target), π_t is actual inflation, and y_t is the output gap. The neutral real interest rate rr_t^* and the output gap y_t are uncertain, particularly in real time. Suppose that π_t can be perfectly observed, and assume for simplicity that inflation is on target, i.e., $\pi_t = \pi^* = 2$. Suppose that the MPC members' individual estimates of r_t^* and y_t are as in table 1.

Then voting directly on the interest rate (a *conclusion-based procedure*, or CBP) gives $r_t = 4.5$. However, the majority view of the premise variables together with the Taylor rule (a *premise-based procedure*, or PBP) gives $r_t = 4.0$, and there is a discursive dilemma.

Suppose now that the MPC uses CBP to decide on the interest rate. What should then be the story explaining this decision? The majority story cannot be used, as there is a discursive dilemma. Nor can the average story be used, as that story is also inconsistent with $r_t = 4.5$. The strategy that seems closest at hand is therefore to take the story of the winner of the vote on the interest rate. If amended with a rule that says which story to choose if there are several stories consistent with the median interest rate, this strategy will always provide one story that is consistent with the decision. It is, however, arguable whether this story represents the "center of gravity" of the committee. Furthermore, the estimates (judgments) in that story can be inefficient and biased. There is no aggregation of information behind the story, and hence no reason to expect that it will be a good one.[1] For instance, the winner of the vote on the interest rate may have an extreme view on inflation, but the effect of this view on his preferred interest rate may be offset by an equally extreme view on unemployment, putting his view on the interest rate close to the average view. The communication of such extreme views is bound to be cumbersome.

We therefore argue that from a communication point of view, PBP is better. First, explaining the level of the interest rate chosen is always easy because it can be inferred directly from the committee's median view on the underlying variables, and the story will always represent the center of gravity in the committee. Second, PBP results in more precise stories, because the central bank's views on the underlying variables are then median (noisy) observations of the true values of the macro variables. These views are close to the true values of the variables, as there is aggregation of information behind them.

The analysis in the paper proceeds in three steps. In section 2 we define some useful terminology and present a general proposition on the existence of the discursive dilemma. In section 3 we discuss

[1]When discussing information aggregation in committees, it is useful to distinguish between "pooling by talking" and "pooling by voting" (Claussen et al. 2012). In this paper we consider pooling by voting.

different alternatives for finding a story under CBP. In section 4 we analyze the quality of the stories under CBP and PBP. Using simulations, we show that PBP clearly yields a better story. In section 5 we discuss some of the assumptions behind our analysis.

1.1 Literature

In an earlier paper (Claussen and Røisland 2014), we study the quality of the policy decision under PBP and CBP. In this paper we ask how well the decisions can be explained to the public and study the quality of the story explaining the decision under the two decision-making procedures. The paper is related to the literature on central bank communication (see, e.g., Blinder et al. 2008) and the recent literature on the discursive dilemma.

There is by now a growing literature on the discursive dilemma. An important finding is that the dilemma is not just an artifact of majority decisions and special examples, but represents a general challenge for groups making decisions on the basis of judgments on a set of issues. See, e.g., List and Puppe (2009) and List and Polak (2010) for overviews of the literature on binary judgment aggregation, and Claussen and Røisland (2010) for some general characterization results for non-binary aggregation.

There are only a few papers on the merits of PBP versus CBP. Pettit (2001) and Chapman (2003) apply a *procedural* perspective and argue that decisions should be made for the right reasons, which, in their view, favors PBP. The second perspective, suggested by Bovens and Rabinowicz (2004), is *epistemic*: The best procedure is the one that is most likely to give the correct decision, irrespective of the underlying reasons. From this perspective, it does not matter whether a decision is reached through incorrect judgments of the premises, as long as the decision itself is correct. In our previous paper, Claussen and Røisland (2014), we apply an epistemic perspective and analyze which of the two alternative decision procedures result in better monetary policy decisions in terms of the smallest mean squared error for the interest rate. In the current paper we take the procedural perspective and look at which procedure gives the best aggregate judgment on the reasons for the decision. These two papers are the only studies in the literature that investigate the merits of the two procedures when judgments are non-binary. List (2005) looks at dichotomous (yes/no) judgments from both the procedural and the epistemic approach. His simulation results, where the group aggregates by majority voting, show that PBP tends to be better than CBP from both a procedural and epistemic perspective. Our simulation results give the same results for non-binary judgments. We even find that in situations when PBP and CBP are equal in terms of interest rate decisions (epistemic perspective), PBP produces better stories (procedural perspective).

2. Analytical Framework

We consider an MPC that consists of n members, where n is an odd number.

A *reaction function,*

$$r = R(x_1, x_2, \ldots, x_m), \tag{2}$$

is a function that gives the interest rate as a function of a set of input variables $x_1, x_2, \ldots, x_m$. Reaction functions can be the result of optimizing an objective (loss) function, or they can represent simple policy rules. The input variables in the reaction function could be measures of underlying inflation, the output gap, financial conditions, etc. MPC members may have different estimates or judgments of the input variables $x_1, x_2, \ldots, x_m$.

We assume that individual MPC members' reaction functions share the common general functional form $R(\cdot)$ but allow for individual-specific values of the parameters in the function. MPC members may have different parameter values, as they have different policy preferences, different estimates, and different judgments on economic mechanisms.

Following Claussen and Røisland (2014), we call parameters and variables in R to which members may have different judgments or estimates *premise variables.* The relation between r and the premise variables is given by a *dependence function,*

$$r_j = D(p_{1,j}, p_{2,j}, \ldots, p_{k,j}) \quad j = 1, \ldots, n, \tag{3}$$

where r_j is MPC member j's judgment of the appropriate interest rate, $p_{i,j}$ is member j's judgment or estimate of premise variable i, and k is the number of premise variables. Variables and parameters that are relevant for r, but which the members of the MPC always agree on, may be represented by the functional form of D. Suppose, for instance, that $r = \alpha x$ is a reaction function, x is the rate of underlying inflation, and α is a parameter for how much a change in x should affect r. Then, the dependence function is the reaction function if MPC members always agree on the value of α. Otherwise, the dependence function has two arguments: x and α. Note that in the latter case the dependence function will be non-linear even though the reaction function is linear. Note also that the MPC members agree by construction on $D(\cdot)$. The dependence function is just an analytical device, and the assumption that all members agree on the dependence function should be uncontroversial as long as one assumes that all members' reaction functions share the same functional form. We discuss the assumption of a common functional form for the reaction function in section 5.

A *story* S is a vector of estimates or judgments on the (sequence of) premise variables $p_1, p_2, \ldots, p_k$. We say that *a story S explains an interest rate r* if

$$r = D(S). \tag{4}$$

We assume that members of the MPC are rational such that individual stories explain individual interest rate judgments, i.e.,

$$r_j = D(S_j), \tag{5}$$

for all $j \in \{1, 2, \ldots, n\}$ and where S_j is the story of MPC member j.

We assume that the MPC uses majority voting, since this is most frequently used by MPCs in practice.[2] Furthermore, we assume that members' preferences over each variable are single-peaked around each member's best estimate or best judgment of the variable.[3] By the median voter theorem, the outcome of a pairwise majority vote

[2] Majority voting has the advantage that it is robust to strategic behavior (Black 1948). This property, together with its simplicity, probably explains its popularity.

[3] By "preferences" over variable j (or the policy variable) we mean a complete, transitive, and weak order on P_j where $P_j \subseteq \mathbb{R}$ is the set of alternative values for premise variable j (or on a set $Y \subseteq \mathbb{R}$ of alternatives for r). The term "preference" should not be taken literally. All we assume is that each member can, for

over the alternative values for a variable is then the median of the individual estimates or judgments for the variable. These medians are denoted p_j^m and r^m, i.e.,

$$p_i^m = median(p_{i,1}, \ldots, p_{i,n}), i = 1, \ldots, k$$

and

$$r^m = median(r_1, \ldots, r_n).$$

We call the story that follows from a vote over each of the premise variables the *median story* and denote it S^m, i.e.,

$$S^m = (p_1^m, \ldots, p_k^m) .$$

There is a *discursive dilemma* if the median story does not explain the median interest rate, i.e., if

$$r^m \neq D(S^m).$$

Situations where the discursive dilemma may occur are then characterized by the following proposition.

PROPOSITION 1. *The MPC may face a discursive dilemma if and only if (i) there is more than one premise variable, or (ii) the dependence function $D(\cdot)$ is (weakly) non-monotonic.*

Proof. See Claussen and Røisland (2014).

3. Consistent Communication

3.1 Conclusion-Based Procedure

The *conclusion-based procedure* (CBP) is a procedure where the MPC's interest decision is the outcome of a direct vote on the interest rate, such that the interest rate decision is given by r^m.

---

any two distinct alternatives $x, z \in P_j$ (or Y), say that she weakly "prefers" x to z (or z to x). The definition does not say anything about *why* she "prefers" x to z. Member i could, for instance, prefer x to z because she finds that x gives her higher utility than z, she could prefer x to z because she believes that x is closer to the true value of the variable than z (it is a "better estimate"), or—if variable j is a policy variable—she could prefer x to z because she finds that x gives higher social welfare than z.

When there is no discursive dilemma, the median story explains the decision as $r^m = D(S^m)$. Suppose now that there is a discursive dilemma, i.e., that $r^m \neq D(S^m)$. How can the committee arrive at a story that explains the decision and that is representative of the committee view?

In the United States, the Federal Open Market Committee (FOMC) publishes the "central tendency" of the individual estimates and forecasts. In the example in table 1 in the Introduction, the midway between the highest and lowest estimates, $rr^* = 2.25$ and $y = 0.5$, can be interpreted as some kind of central tendency. Interestingly, this central tendency story is consistent with $r = 4.5$. However, this is generally not the case. It is easy to make examples where this definition of the central tendency does not produce a consistent story.[4] The same holds for other central tendency rules, such as "average rules" based on linear combinations of individual judgments.[5]

In the numerical analysis below, we assume that the story communicated under CBP is the story of the winner of the vote on the interest rate. This strategy will always result in a consistent story if it is amended by a lottery, seniority rule, or some other rule that picks one story if there are several stories behind the median interest rate. However, it is sometimes arguable whether this story represents the center of gravity within the committee. Furthermore, the communication of this story can be very cumbersome, as the median interest rate may follow from extreme views on the premise variables. We could, for instance, have a situation where the winner of the vote on the interest rate has an extreme view of the inflation outlook, which in isolation calls for a high interest rate, but also has an extreme view of the outlook for unemployment, which calls for a low interest rate, making his (net) judgment of the interest rate the median. Thus, the communication of stories can be difficult if there is a discursive dilemma and the interest rate decision is based on a direct vote on the interest rate. Furthermore, the estimates and

[4]Let, for instance, three individual judgments on rr^* and y be (2.1), (2.5), and (3.2), which gives $r^m = 4.5$. The central tendency is then $(2.5, 1)$, which gives $r = 5.0$.

[5]In the example in the Introduction, the average story is $(2.17, 0.33)$, which gives $r = 4.32$.

forecasts in that story do not necessarily represent efficient judgment aggregation, as it is only the story of one member. If we have to pick one member to find the story, the median interest rate member would usually be the best one to pick, but there is no aggregation of information behind that story, and hence no reason to expect that it will be a good one. We return to this point in section 4 below.

3.2 Premise-Based Procedure

Under the *premise-based procedure* (PBP), the interest rate decision is the interest rate that follows from the outcome of a vote on the premise variables together with the dependence function,

$$r^P = D\left(S^m\right).$$

With this procedure, explaining the level of the chosen interest rate is always easy, as the decision is always explained by the median story. Furthermore, as the story is the median story, it also represents the "center of gravity" of the MPC.

4. The Quality of the Story

In addition to explaining the decision and reflecting the "center of gravity" of the MPC, a desirable property for the story is that it should be precise in the sense that it is close to the true story, i.e., the story that consists of the true (but unobservable) values of the premise variables. Although there are examples in the theoretical literature where precise communication could be counterproductive—e.g., as shown by Morris and Shin (2002)—we believe that in practice, central banks want their published judgments and estimates to be as precise as possible. Having precise estimates and making good judgments enhances the credibility of the central bank.

To assess the relative performance of CBP and PBP, we conduct a simulation exercise to evaluate the precision of the judgments of the premise variables implied by each procedure. We assume that each individual's noisy observation ("judgment") of premise variable i is drawn independently from a given distribution to be specified below.

We assume that the individual judgments are unbiased, so that the mean of the distribution of the individual judgments is the true (but unobservable) value of the premise variable. For each realization of the individual judgments, we construct the median premise and, using a dependence function described below, we derive the median interest rate that would be chosen under CBP and the rate implied by the median premises under PBP. Since the distribution of the median does not have an analytical expression for small samples, we base our analysis on Monte Carlo simulations, where we use 10,000 draws of individual judgments. In this section we use the terms "judgment" and "estimate" synonymously, but since we do not specify how they are formed, we treat them as noisy observations. We measure the precision of a story by the root mean squared error (RMSE) of the judgments of premise variables. In order to obtain a measure that is independent of the degree of noise in the individual judgments, we divide this measure by the RMSE of the distribution for p_i, i.e., the standard deviation of the distribution, denoted σ_{p_i}. Denote this relative RMSE under PBP $relRMSE(p_i^m)$, i.e.,

$$relRMSE(p_i^m) = \frac{\sqrt{\frac{1}{10000}\sum_{t=1}^{10000}(p_{i,t}^m - p_i)^2}}{\sigma_{p_i}},$$

where p_i is the true value of premise variable i and p_i^m is the median noisy observation (judgment) of p_i. Similarly, denote the relative RMSE under CBP $relRMSE(p_i^{r^m})$, where

$$relRMSE(p_i^{r^m}) = \frac{\sqrt{\frac{1}{10000}\sum_{t=1}^{10000}(p_{i,t}^{r^m} - p_i)^2}}{\sigma_{p_i}},$$

and where $p_i^{r^m}$ is the judgment of premise variable i of the winner on the vote on r. Thus, if the premise variable in the story communicated by the MPC is just as (in-)accurate as the individual judgments on the premise variable, then $relRMSE = 1$. If the MPC's aggregate story provides value added relative to a random individual's story, then $relRMSE < 1$. We say that *the smaller relRMSE is, the more precise are members' judgments on* p_i.

4.1 Linear Dependence Functions

Consider first the general linear dependence function, i.e.,[6]

$$r = p_1 + p_2 + \cdots + p_k. \tag{6}$$

We assume that the individual judgments $p_{h,j}$ of each premise variable p_h are normally distributed with the mean equal to the true value of p_h, i.e., $p_{h,j} \sim N(p_h, \sigma_h^2)$ for all $j = 1, 2, \ldots, n$ and all $h = 1, 2, \ldots, k$. We will treat premise variables symmetrically. It therefore suffices to report the *relRMSE* for one of the premise variables to evaluate the informational value of the story. Note also that with a linear dependence function, PBP and CBP are normatively equal if we only look at the precision of the interest rate decision, c.f. Claussen and Røisland (2014). The results of the simulations are summarized in table 2. Recall that for linear dependence functions, there can only be a discursive dilemma if $k \geq 2$, c.f. proposition 1.

We see that *relRMSE* is considerably smaller when each premise variable is voted on than when we let the median voter on the interest rate dictate the story, i.e., $relRMSE(p_i^m) < relRMSE(p_i^{r^m})$. Generally, we see that *relRMSE* decreases with the number of MPC members. This is akin to the Condorcet jury theorem, which follows from the law of large numbers. This gain from committees has been launched as an explanation of why we have monetary policy committees (see, e.g., Gerlach-Kristen 2006). When the individual judgment errors are unbiased and not perfectly correlated, $relRMSE(p_i^m) \longrightarrow 0$, as $n \longrightarrow \infty$ when the MPC votes on each premise variable. However, if the MPC's story is the story chosen by the median voter on the interest rate, the gain from increasing the number of members becomes smaller and, interestingly, does not converge to zero. Actually, in our simulations $relRMSE(p_i^{r^m})$ never falls below 0.70 irrespective of how large n is. We also see that $relRMSE(p_i^{r^m})$ increases with the number of premise variables. Thus, with CBP, the quality of the story decreases when the story becomes more complex. This is in contrast to PBP, where the quality of the story is independent of the number of premise variables.

[6]The lack of coefficients on the premise variables does not limit the generality, as we may define a given premise variable as the product of the coefficient and the underlying premise variable, i.e., $p_j = \alpha\tilde{p}_j$. Equation (6) is linear as long as there is disagreement about either the coefficient or the variable, but not both.

Table 2. Relative RMSE of a Premise Variable in a Story under CBP and PBP and a Linear Dependence Function

	$n = 3$		$n = 5$		$n = 7$		$n = 11$		$n = 101$	
	CBP	**PBP**	**CBP**	**PBP**	**CBP**	**PBP**	**CBP**	**PBP**	**CBP**	**PBP**
$k = 2$	0.84	0.67	0.80	0.54	0.77	0.46	0.75	0.37	0.71	0.12
$k = 5$	0.95	0.67	0.93	0.54	0.92	0.46	0.90	0.37	0.90	0.12
$k = 10$	0.98	0.67	0.97	0.54	0.96	0.46	0.96	0.37	0.96	0.12
$k = 100$	1.00	0.67	1.00	0.54	1.00	0.46	1.00	0.37	1.00	0.12

To summarize the results, we find that a story based on a premise-based procedure represents a better collective judgment on the premise variables than a story that is consistent with a conclusion-based procedure. Thus, even though CBP and PBP result on average in equally good decisions when the dependence function is linear, the stories that are consistent with each procedure do not have equal quality. To the extent that the quality of the communicated story has positive welfare effects, our results give support to a premise-based procedure over a conclusion-based procedure.

4.2 A Non-Monotonic Dependence Function

Above we found that voting on each premise variable produces better stories when there is more than one premise variable. However, as shown by Claussen and Røisland (2014), CBP and PBP may also result in different decisions if there is only one premise variable, and this enters non-monotonically in the dependence function. This might be seen as a special case, but policymakers may in fact often face this situation, as we shall see in the following application.

Suppose that the MPC's objectives can be represented by a (per-period) loss function

$$L_t = \pi_t^2 + \lambda y_t^2, \tag{7}$$

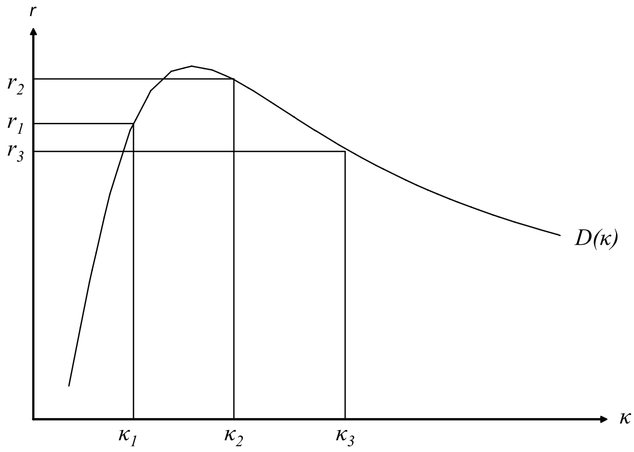
and that the MPC members' view on the economy can be summarized by a simple New Keynesian model, i.e.,

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + u_t, \tag{8}$$

$$y_t = E_t y_{t+1} - (r_t - E_t \pi_{t+1}). \tag{9}$$

Equation (8) is the New Keynesian Phillips curve, where u_t is a cost-push shock, for instance, stemming from stochastic variations in firms' market power. We assume that $E_{t-1} u_t = 0$. Equation (9) is a dynamic IS curve, which can be derived from the Euler equation for an optimal consumption path. We assume for simplicity a unit coefficient on the interest rate, and disregard stochastic fluctuations in the neutral real interest rate (or "demand shocks").

Figure 1. The Discursive Dilemma under Disagreement on κ



The first-order condition for optimal time-consistent policy is[7]

$$\kappa\pi_t + \lambda y_t = 0. \tag{10}$$

Since the shock is not autocorrelated, a discretionary policy is characterized by $E_t\pi_{t+1} = E_t y_{t+1} = 0$. The optimal interest rate is then given by

$$r_t = \frac{\kappa}{\kappa^2 + \lambda} u_t. \tag{11}$$

Assume that the MPC members agree on the size of u_t and λ, but disagree on the size of κ. The only premise variable in the dependence function is then κ. This dependence function is illustrated in figure 1, where we see that $D(\kappa)$ is non-monotonic.

Suppose that $n = 3$, and that the members have judgments on κ as in the figure. If the winner of the interest rate vote (CBP leading to r_1) decides the story, the story becomes $S = \kappa_1$, while if the MPC votes on κ (PBP), the story becomes $S = \kappa_2$.

[7]Under commitment to the timeless perspective, the level of the output gap is replaced by the change in the output gap; see Clarida, Gali, and Gertler (1999).

Table 3. Relative RMSE of a Premise Variable in a Story under CBP and PBP and a Non-Monotonic Dependence Function

	$n = 3$	$n = 5$	$n = 7$	$n = 9$	$n = 11$	$n = 1{,}001$
CBP	0.94	0.92	0.91	0.91	0.91	0.97
PBP	0.78	0.66	0.57	0.52	0.48	0.05

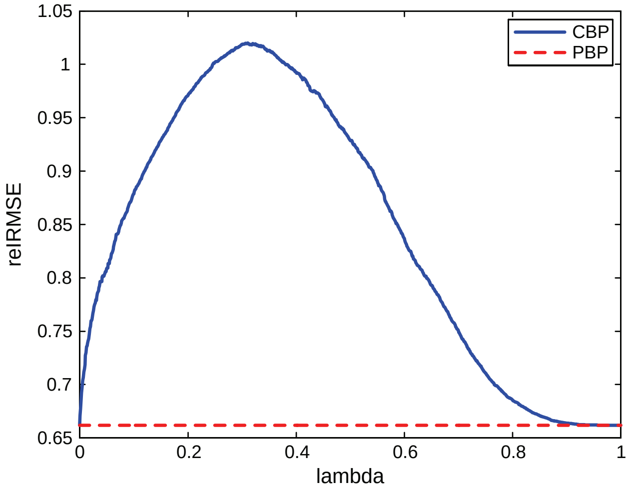
To investigate which story is most precise, we perform similar Monte Carlo simulations as above. Specifically, we assume that the individual judgments on κ have a $beta(1, 1)$ distribution. The motivation for assuming a *beta* distribution rather than a normal distribution is that we want to avoid negative judgments of κ. It is reasonable to assume that although the members disagree about the *size* of κ, they agree about its *sign*, i.e., that a higher output gap gives rise to higher and not lower inflation. We then conduct 10,000 draws to compute the *relRMSE* for each procedure and for different sizes of the MPC. Table 3 shows the simulation results for the case where $\lambda = 0.5$.[8]

As in the previous simulations, we see that voting on κ results in a far more precise story than letting the median voter on the interest rate decide the story. While PBP takes advantage of the committee gain (Condorcet theorem), so that the noise in the MPC's story disappears as n becomes large, this is not the case with CBP.

Figure 2 shows the *relRMSE* for the two approaches as a function of λ in the case where $n = 5$. The two approaches are equal if λ is close to zero or close to one or above. The reason is that in these cases, virtually all of the judgments fall on the monotonic part of $D(\kappa)$, such that there will be no discursive dilemma. An interesting observation is that $relRMSE(p_i^{r^m}) > 1$ for some values of λ. This means that letting the winner of the interest rate vote decide the story results in a worse story than letting a completely random member decide (in which case $relRMSE = 1$). The intuition for this can be seen in figure 1 above. If the true value of κ is in an area near

[8]The qualitative results are independent of the choice of λ, but the magnitude of the difference between the two approaches depends on λ.

Figure 2. *relRMSE* under CBP and PBP as a Function of the Relative Weight on Output in the Loss Function



the maximum of $D(\kappa)$, members who have judgments of κ close to the true value will very rarely be the median voter on the interest rate. Members who have very low or very high judgments of κ will often become the median voter on the interest rate, which gives a bias towards more noisy stories.

In the model above, we have implicitly assumed that the MPC members are certain about their own judgments, such that they do not take parameter uncertainty into account. If they did so, certainty equivalence would not hold, and there would be an additional term σ_κ^2 in the denominator in equation (11), which is the variance of the judgment errors.[9] However, this would not change the results as regards the quality of the story, since we can take this into account simply by replacing λ in equation (11) with $\tilde{\lambda} = \lambda + \sigma_\kappa^2$. Taking parameter uncertainty into account would only make our results more general, as this would also make the dependence function following from disagreement about the coefficient on the interest rate in the IS curve (9) non-monotonic, as shown in Claussen and Røisland (2014).

[9]See Claussen and Røisland (2014).

To summarize, we find that PBP results in a story which tends to be considerably closer to the (unobservable) truth than a story consistent with CBP. In Claussen and Røisland (2014) we found that unless the MPC members are sufficiently overconfident, PBP tends to yield better interest rate decisions than CBP. Here, we have shown another argument in favor of premise-based decision making that is robust to the degree of overconfidence, and which also applies to linear dependence functions.

5. Discussion

5.1 Model Disagreement

In the above analysis, we assumed that the MPC members shared the same general model. This could be a relevant assumption for central banks that have dedicated a particular model in their suite of models as their core model for forecasting and policy analysis, such as the Bank of England, Bank of Canada, and Norges Bank. Without a particular core model, MPC members' policy views might to a larger degree reflect different model beliefs. However, the discursive dilemma is a general phenomenon, and it is likely to be even more prevalent when there is disagreement over models. To see this, consider the following example with an MPC with three members who only care about inflation (i.e., $\lambda = 0$ in (7)). Member 1 believes in the New Keynesian model outlined in sub-section 3.2. Member 2 believes in backward-looking expectations and uses the following equations for inflation and the output gap:

$$\begin{aligned} \pi_{t+1} &= \pi_t + \alpha_y y_t \\ y_t &= \rho_y y_{t-1} - \gamma(r_t - E_t \pi_{t+1}). \end{aligned}$$

The third member is a monetarist and believes

$$\begin{aligned} \pi_{t+1} &= \alpha_m (m_t - m_{t-1}), \\ m_t &= p_t + y_t - \delta r_t, \\ y_t &= \tau y_{t-1} - \varphi(r_t - E_t \pi_{t+1}), \end{aligned}$$

Table 4. Individual Judgments and Preferences over Models

	Pref. over Models	u_t	r_t
Member 1	$M1 \succ M2 \succ M3$	1	$1/\kappa$
Member 2	$M2 \succ M1 \succ M3$	1	0
Member 3	$M3 \succ M1 \succ M2$	0	0
Majority	$M1 \succ M2 \succ M3$	1	0

where m_t is the money stock and p_t is the price level. The reaction functions for the three members then become

$$\text{New Keynesian model } (M1)\text{: } r_t = \frac{1}{\kappa} u_t \tag{12}$$

$$\text{Backward-looking model } (M2)\text{: } r_t = \frac{1}{\alpha_y \gamma} \pi_t + \frac{\rho_y}{\gamma} y_{t-1} \tag{13}$$

$$\text{Monetarist model } (M3)\text{: } r_t = \frac{1}{\delta + \varphi} (p_t - m_{t-1} + \tau y_{t-1}). \tag{14}$$

Suppose now that members are able and willing to rank and vote over the alternative models, and then use the winning model/reaction function as the basis for the premise-based decision. Suppose that all historical values, π_t, and p_t are observable and put $y_{t-1} = (p_t - m_{t-1}) = \pi_t = 0$. Let the preferences over models and judgments of u_t be as in table 4. Then PBP gives $r_t = 1/\kappa$ while CBP gives $r_t = 0$, and there is a discursive dilemma. Note also that in this case there would not have been a discursive dilemma if all three members believed in the same model. This illustrates how the discursive dilemma is reinforced with model disagreement.

The communicational challenges under CBP are even more severe when there is model disagreement. Finding a story that explains the majority interest rate decision and represents the center of gravity of views in the committee is difficult, if not impossible, if there is disagreement about the model. Furthermore, if the committee decides to communicate the story of the winner of the vote on the interest rate, the model in the story that explains the decision may change from decision to decision even if members' preferences over models stay the same: At one meeting it might be the New Keynesian that wins the vote over r. At the next meeting it might be the monetarist, and so on. Monetary policy might therefore appear random and inconsistent over time.

But also PBP becomes more difficult. One problem is that now we might also get a "traditional" voting paradox. If, for instance, member 3 has the preferences $M2 \succ M3 \succ M1$, there is no (Condorcet) winner when voting over models, i.e., no model beats all other models in a pairwise vote over models. Furthermore, PBP might be implausible, as a fundamental disagreement over models simply entails that MPC members are unwilling to base their judgment of the interest rate on any model other than their own. Under fundamental disagreement, the committee might therefore consider alternative communication strategies. We discuss two of these below.

5.2 Partially Premise-Based Decisions

We have so far considered the fully conclusion-based versus the fully premise-based decisions. The motivation was that assuming the alternative procedures in their clean forms facilitates a clean comparison between the two. However, while fully conclusion-based decisions are obviously realistic, it is arguable whether truly premise-based decisions are possible in practice. First, full PBP could be cumbersome and time consuming. Second, as discussed above, full PBP can be difficult, if not impossible, if there is disagreement about models. Third, some members may have a more intuition-based approach to monetary policy and are not able or willing to formulate their models in a precise way.

To consider the more realistic intermediate case of partial PBP, assume that member j's preferred interest rate is given by

$$r_j = D(S_A^j, S_B^j),$$

where $S_A = (p_1, \ldots, p_h)$ is a vector of premise variables that are subject to aggregation of judgments within the MPC, and $S_B = (p_{h+1,\ldots,}p_k)$ is a vector of premise variables that are not subject to such aggregation. These could, for instance, be premise variables that are not judged to be crucial for the central bank's story, or variables that are too difficult to formulate in a sufficiently precise way. This may, for instance, capture the case where members believe in different models, so that the parameters and variables describing the models are embedded in S_B. Note that we do not require the elements in S_B to be observable. In fact, if the subset of S_B^j represents parameters and variables representing member j's view of the economic mechanisms (his "model"), but the member is not able to formulate his model precisely, the elements of S_B^j could be unobservable also to member j. We assume, however, that it is *in principle* possible to formulate his model precisely, although the member is not able to do so.

In this setting it is not possible to perform full PBP, but a partial procedure is still viable as a two-step decision procedure. The first step is that the MPC votes over each premise variable in S_A. The outcome of the vote, given our assumptions outlined in section 2, will then be the median of each element in S_A. Denote the vector of median judgments S_A^m. The individually preferred interest rates conditional on the aggregate judgments of S_A are

$$r_j = D(S_A^m, S_B^j), \quad j = 1, \dots, n.$$

In the second step, the MPC votes over the alternative preferred interest rates conditional on $S_A = S_A^m$. The decision will then be the median of the conditional preferred rates:

$$r_{m|P_A^m} \equiv median[D(S_A^m, S_B^1), D(S_A^m, S_B^2), \dots, D(S_A^m, S_B^n)].$$

To explain the story, the central bank may now communicate the story $S = (S_A^m, S_B^{m|P_A^m})$, where $m|P_A^m$ denotes the member who holds the median preferred interest rate conditional on P_A^m. In practice, central banks do not convey a complete story, i.e., a set of information sufficient for the public to make a perfect mapping between S and r. Instead, they may communicate elements of the story that are considered key arguments for the decision. One possibility is to communicate only the elements of the story that have been subject to aggregation, i.e., S_A^m. Then, the (incomplete) story reflects by construction the "center of gravity" of the MPC. The story is also *consistent* with the decision. It does not, however, *explain* the decision, as defined in equation (4), without communicating $S_B^{m|P_A^m}$. Still, the elements of the story that are communicated—i.e., S_A^m—hold the same precision as under full PBP, as analyzed in section 4. Thus, even if full PBP may not always be possible or desirable, the central bank does not necessarily have to resign to full CBP.

A partial procedure will still give better communication than CBP if one wants the story to be precise and represent the center of gravity of the MPC.

5.3 Why Not Communicate All the Individual Stories?

In the above analysis, we have assumed that the central bank publishes only one story. Why not communicate all the individual stories?

Generally, one might view more information as better than less. If members' individual judgments have informational value to private agents, publishing all the members' individual stories would, arguably, be beneficial. However, in reality central banks seem to focus on one story in their communication. The Bank of England and the Riksbank, for instance, publish minutes from the interest rate meetings where individual judgments are provided.[10] These minutes could be regarded as publishing parts of the individual stories. But, nevertheless, the forecasts and analyses in the inflation or monetary policy reports of these two central banks represent one story which is supposed to be the central tendency view of the MPC. Some central banks, such as Norges Bank, do not publish minutes but provide one story in the monetary policy report that is supposed to fully explain the interest rate decision. The Federal Reserve publishes the distribution of individual forecasts from the FOMC members but does not provide the details and the assumptions behind the individual forecasts. In the press release immediately after the FOMC meeting there is one story. Thus, there appears to be a strong tendency for central banks to focus on one story in their communication.

Our analysis does not provide any answer as to why central banks tend to focus on one story. But, one reason could be what Blinder (2007) called the "cacophony problem": "A central bank that speaks with a cacophony of voices may, in effect, have no voice at all." While Blinder did not provide a theoretical rationale for the cacophony problem, Moscarini (2007) shows that a central bank can gain credibility and increase its ability to affect expectations if it appears competent. He argues that publishing conflicting views among MPC

[10] At the Bank of England, the minutes are not attributed, as opposed to at the Riksbank.

members can make the central bank appear less competent in the view of the public and thereby less credible.

We have also assumed that central banks want the communicated story to be consistent with the decision and as precise as possible. Although we do not model the relationship between communication, competence, and credibility, it seems reasonable to think that a central bank that publishes a story that is inconsistent with the decision will hardly appear competent and credible. We therefore find it reasonable to assume that the central bank would like the story to be consistent with the decision, and that the quality of the story should be as high as possible.

5.4 Strategic Voting

We have implicitly assumed that the MPC members report their true judgments. The assumption is important, as PBP will not work if members act strategically. To see this, consider member 1's judgment on κ in figure 1. Under PBP, the interest rate will be r_2 if members do not act strategically. But, if member 1 instead reported a judgment of κ which lies between κ_2 and κ_3, member 1 would become the median voter and dictate r. The other members would then not have any incentives to deviate, i.e., we would have a Nash equilibrium, and PBP would yield the same result as CBP.

We nevertheless think it is useful to assume that MPC members do not act strategically. One reason is that it is necessary to know how things work when people do not act strategically before analyzing how things work under strategic behavior. Another reason is that it seems, arguably, somewhat odd to assume that MPC members will behave strategically in this way. First, the Nash equilibrium above requires that members know each other's true preferences and accept that they do not vote according to these. It does not seem reasonable to assume that MPC members will exploit the voting system and openly behave strategically in this way. Second, and related to the first point, there are social norms in MPCs that probably limit such strategic behavior. Third, MPC members also care about making good judgments of the premises for the decision. In the example above, the median judgment of κ is closer to member 1's best judgment on κ than the κ that will be in the story if member 1 behaves strategically. Thus, if members care not only about the interest rate decision but also about the quality of the story, they will have incentives not to behave strategically.[11]

References

Black, D. 1948. "On the Rationale of Group Decision-making." *Journal of Political Economy* 56 (1): 23–34.

Blinder, A. S. 2007. "Monetary Policy by Committee: Why and How?" *European Journal of Political Economy* 23 (1): 106–23.

Blinder, A. S., M. Ehrmann, M. Fratzscher, J. De Haan, and D. J. Jansen. 2008. "Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence." *Journal of Economic Literature* 46 (4): 910–45.

Bovens, L., and W. Rabinowicz. 2004. "Democracy and Argument: Tracking Truth in Complex Social Decisions." In *Deliberation and Decision*, ed. A. Van Aaken, C. List, and C. Luetge. Aldershot: Ashgate Publishing.

Chapman, B. 2003. "Rational Choice and Categorical Reason." *University of Pennsylvania Law Review* 151 (3): 1169–1210.

Clarida, R., J. Gali, and M. Gertler. 1999. "The Science of Monetary Policy: A New Keynesian Perspective." *Journal of Economic Literature* 37 (4): 1661–1707.

Claussen, C. A., E. Matsen, Ø. Røisland, and R. Torvik. 2012. "Overconfidence, Monetary Policy Committees and Chairman Dominance." *Journal of Economic Behavior and Organization* 81 (2): 699–711.

Claussen, C. A., and Ø. Røisland. 2010. "A Quantitative Discursive Dilemma." *Social Choice and Welfare* 35 (1): 49–64.

———. 2014. "The Discursive Dilemma in Monetary Policy." *Scandinavian Journal of Economics* 116 (3): 702–33.

Gerlach-Kristen, P. 2006. "Monetary Policy Committees and Interest Rate Setting." *European Economic Review* 50 (2): 487–507.

[11] We may distinguish between "reason-oriented" and "outcome-oriented" MPC members. The distinction is closely related to the distinction between a procedural and an epistemic perspective on decision making mentioned in the Introduction. Outcome-oriented members behave strategically under the PBP, while reason-oriented members do not.

Kohn, D. L. 2001. "The Kohn Report on MPC Procedures." *Quarterly Bulletin* (Bank of England) 41 (1): 35–50.

List, C. 2005. "The Probability of Inconsistencies in Complex Collective Decisions." *Social Choice and Welfare* 24 (1): 3–32.

List, C., and B. Polak. 2010. "Introduction to Judgment Aggregation." *Journal of Economic Theory* 145 (2): 441–66.

List, C., and C. Puppe. 2009. "Judgment Aggregation: A Survey." In *The Handbook of Rational and Social Choice*, ed. P. Anand, P. Pattanaik, and C. Puppe. Oxford: Oxford University Press.

Morris, S., and H. S. Shin. 2002. "Social Value of Public Information." *American Economic Review* 92 (5): 1521–34.

Moscarini, G. 2007. "Competence Implies Credibility." *American Economic Review* 97 (1): 37–63.

Pettit, P. 2001. "Deliberative Democracy and the Discursive Dilemma." *Philosophical Issues* (a supplement to *NOÛS*) 11 (1): 268–99.

Do Publicly Owned Banks Lend Against the Wind?*

Thibaut Duprey
Paris School of Economics and Banque de France

This paper investigates the lending pattern of state-owned banks over the business cycle. I take the endogeneity of public banking into account by including records on both privatizations and nationalizations during banking crises. I find that public bank lending is (i) significantly less cyclical except for low-income countries, (ii) asymmetric along the business cycle, (iii) heterogeneous across stages of economic development, and (iv) related to banks' vulnerability on their funding side. Public banks reduce their lending less during economic downturns, but their ability to absorb negative shocks is marginally decreasing as the size of the shock increases.

JEL Codes: G21, G28, G32, H44.

1. Introduction

Since the seminal paper by La Porta, Lopez-de-Silanes, and Shleifer (2002),[1] which accompanied the wave of privatizations in the 1990s, it has been widely accepted that state-owned banks (hereafter public

*The opinions expressed herein do not necessarily reflect the position of the Banque de France. This paper was previously circulated under the title "Bank Ownership and Credit Cycle: The Lower Sensitivity of Public Bank Lending to the Business Cycle." I am grateful to Jean Imbs, Xavier Ragot, and Romain Rancière for guidance, as well as Vincent Bouvatier, Régis Breton, Balazs Egert, Benjamin Klaus, Mathias Lé, Thomas Piketty, and seminar participants at the Banque de France, the Paris School of Economics, the 2012 CSAEM conference, the 2013 Risks in Finance Conference at Orléans University, the 2013 ADRES-AFSE conference, and the 2nd PhD Conference on International Macroeconomics and Financial Econometrics for helpful comments on previous drafts. E-mail: thibaut.duprey@gmail.com.

[1]See also, for instance, Barth, Caprio, and Levine (2004) or Galindo and Micco (2004).

banks) are a source of long-term inefficiency.[2] However, little is known about the role of public bank lending in the short run over the business cycle, especially in times of crisis when the access to bank loans is more difficult.

In this context, using individual bank balance sheet data over 1990–2010 for eighty-three countries covering at most 366 public banks, the present paper shows that public banking is associated with less cyclical lending policies, especially in the case of economic downturn. However, this effect is reversed for less developed countries, where public banks tend to have a more vulnerable funding structure.

Only a handful of papers have focused on this issue by analyzing short-term variations in credit supply to the economy. First, using a cross-country data set over the period 1995–2002, Micco and Panizza (2006) find that lending by state-owned banks is less correlated with the business cycle. Two case studies provide similar results (Germany from 1987 until 2005: see Foos 2009; South Korea around the 2008 recession: see Leonya and Romeub 2011). Cull and Martinez Peria (2013) present a before/after 2008 analysis and find that public banks reacted in a countercyclical fashion in Latin America, but not in Europe. The present paper is more closely related to the contemporaneous analysis by Bertay, Demirgüç-Kunt, and Huizinga (2015), where they conclude that lending by state banks is less procyclical than lending by private banks, especially in countries with good governance and a high level of economic development. To deal with the endogeneity of public banking, they use a generalized method of moments (GMM) methodology to instrument the public ownership dummy, which becomes time varying as they reconstruct ownership changes from the successive updates of the Bankscope database over the last ten years. In addition, they use indices of governance quality to track the heterogeneity in lending cyclicality across their panel.

The present paper adopts a different but complementary strategy and contributes to the literature in three ways. First, I combine the public bank ownership dummy with records of individual bank

[2]This is partly because public banks fail to screen out good projects, which squeezes interest margins (Sapienza 2004; Allen et al. 2005; Mian 2006; Micco and Panizza 2006; Iannotta, Nocera, and Sironi 2007) and fails to ensure an efficient allocation of credit (Megginson 2005).

privatization events and also with an indicator on bank nationalizations during crises. However, I ignore the intensity of the government's involvement in the bank around privatization events, and I can only single out nationalizations during crises at the country level, without identifying each nationalized bank. Nevertheless, failing to take the endogeneity of public banking into account could bias the results. The real impact of public ownership may be blurred by capturing the negative effect of newly rescued or bailed-out banks appearing as state owned. Likewise, newly privatized banks appear as private but may still be in the process of adjusting their lending behavior.

A second novelty is the focus on asymmetric reactions over the business cycle and heterogeneity across the stages of economic development. Overall, public banks tend to reduce their aggregate lending volumes less during economic downturns, but this stabilizing effect is marginally decreasing as the size of the negative shock increases. This is especially true for middle-income countries, while public banks can be even more procyclical in low-income countries. However, the lower procyclicality of public bank lending in high-income countries is rather the consequence of banks increasing their lending less during phases of expansion. Thus the results show a non-linear relation between economic development and public banks' ability to absorb negative shocks. This finding may appear in contradiction with both the development and political views of public banking,[3] which suggest more countercyclical lending by the public banking sector for countries with lower economic or institutional development. But these studies focus more on either long-term development or short-term fluctuations over the political cycle, not over the business cycle.

Last, I show that this asymmetric and heterogeneous lending pattern of public banks is consistent with the variation in their liabilities. The funding sources of public banks are less procyclical in medium- to high-income countries, with a lower reliance on short-term funds, as well as a lower volatility of wholesale funds in the case

[3]For the development view see, for instance, Gerschenkron 1962 and Barth, Caprio, and Levine 2000. For the political view, see Shleifer and Vishny 1994; Sapienza 2004; Dinc 2005; Khwaja and Mian 2005; and Micco, Panizza, and Yanez 2007.

of a negative macroeconomic shock. Conversely, public banks have a more vulnerable funding structure in low-income countries. However, the different cyclicality of public bank lending could also have other sources, which are beyond the scope of the present paper, such as corporate governance issues, lending relationship management, or loan maturity extensions.

The next section describes the data set, especially the way public banking is handled, and the methodology. Section 3 presents the key results of the paper about the lower cyclicality of public bank lending. Then section 4 investigates the asymmetric and heterogeneous cyclical reactions of public bank lending across the phases of the economic cycle and the stages of economic development. Section 5 shows that funding sources of public banks display similar cyclical properties. Section 6 concludes.

2. Data Set and Methodology

2.1 Data Set Construction

I use Bankscope[4] for bank-specific variables, as well as data from the United Nations Statistics Division (UNSTAT), the World Bank, and Standard & Poor's (S&P) for country-wide variables. I cover the period 1990–2010, but it should be noted that the coverage of the Bankscope data set increased over time and stabilized somewhat in 1999. Even if a single bank rarely remains in the data set over twenty years,[5] I prefer to keep the largest time span of each bank and to start in 1990, which allows me to include many privatization events that took place in the 1990s. I stop in 2010, as this is the last date of my public ownership dummy and I do not have data on public ownership changes after 2009. Tables 1 and 2 describe the variables used.

I focus on the main types of banking institutions (excluding bank holdings), namely commercial, real estate, savings, and investment banks. When banks report multiple balance sheet statements, I use

[4]For a description of issues specific to the Bankscope database and the codes associated with it, see Duprey and Lé (2014).

[5]For instance, due to increased coverage, merger, divestiture, accounting change, or bankruptcy.

Table 1. Variables Definition

Variable	Label	Source
gGDP	Growth of GDP, constant 2005 USD	UNSTAT
OutputPotential	Deviation of GDP from potential GDP in percent of potential GDP	OECD Economic Outlook
OutputGap	Deviation of GDP from its trend (HP filter with smoothing parameter 6.25) over GDP	UNSTAT
gLoan	Growth of gross loans	Bankscope
gLoanCorp	Growth of loans to group companies and other corporate	Bankscope
Size	Log of bank asset in million USD	Bankscope
SizeRel	Asset of one bank relative to top 20 in each country/year	Bankscope
gSizeRel	Growth of *SizeRel*	Bankscope
SizeMarket	Asset top 20 banks of one banking sector relative to the sum of the top 20 in all countries	Bankscope
gSizeMarket	Growth of *SizeMarket*	Bankscope
CR4	Concentration ratio of top 4 banks over top 10	Bankscope
RatingChange	Change of long-term country rating and outlook in foreign currency scale from 1 ("D" and negative outlook) to 69 ("AAA" and positive outlook)	Standard & Poors
GDPperCapita	Log of GDP per capita, constant 2005 USD	UNSTAT
Inflation	Inflation rate	UNSTAT
RealInterestRate	Real interest rate by country	World Bank
chLendingInterestRate	Change end of the year average bank lending interest rate by country	World Bank
gMMF	Growth of money-market funds	Bankscope
gSTfunding	Growth of short-term liabilities defined as: total liabilities—total deposits—long-term funding—reserves	Bankscope

(continued)

Table 1. (Continued)

Variable	Label	Source
gLTfunding	Growth of long-term liabilities	Bankscope
gNonCoreRatio	Growth of the ratio of non-core over core liabilities (customer deposits)	Bankscope
gLLPratio	Growth of the ratio of loan loss provisions over net income	Bankscope
Privatized	Dummy equals one for full/partial privatization of the bank, 1988–2008	World Bank Privatization
BeforePrivatized	Dummy equals one for years before latest privatization wave	World Bank Privatization
GOB_CSH50	Dummy equals one for direct government ownership of more than 50% of the bank:	Bankscope
	– National public controlling shareholder 50%, 2008–10	World Bank Privatization
	– Includes years before privatization recoded as public banks	
GOB_UO50	Dummy equals one for indirect government ownership of more than 50% of the bank:	Bankscope
	– National public ultimate owner 50%, 2008–10	Bankscope
	– National public controlling shareholder 50%, 2008–10	World Bank Privatization
	– Includes years before privatization recoded as public banks	
GOB_UO25	Dummy equals one for indirect government ownership of more than 25% of the bank:	Bankscope
	– National public ultimate owner 25%, 2008–10	Bankscope
	– National public controlling shareholder 50%, 2008–10	World Bank Privatization
	– Includes years before privatization recoded as public banks	
Foreign	Dummy equals one for foreign ownership:	Bankscope
	– Foreign ultimate owner 25%, 2008–10	Bankscope
	– Foreign controlling shareholder 50%, 2008–10	

(continued)

Table 1. (Continued)

Variable	Label	Source
SavingsBank	Dummy for savings bank	Bankscope
InvestBank	Dummy for banks defined as investment banks or investment and trust corporations	Bankscope
RealEstBank	Dummy for banks defined as real estate and mortgage banks	Bankscope
CommercialBank	Dummy for commercial and credit card banks	Bankscope
GvtCreditInstit	Dummy for specialized government credit institutions (all publicly owned)	Bankscope
NatCrisis	Dummy equals one if nationalizations occurred during a banking crisis:	La Porta, Lopez-de-Silanes, and Shleifer (2002)
	– From 1970 to 1995	World Bank Banking Crises
	– From 1980 to 2003	
NatIn2008	Dummy banks nationalized during the 2008–10 systemic banking crisis	IMF Systemic Banking Crises

Table 2. Summary Statistics

Summary statistics are displayed for all banks and then split for the sample of private and public banks, where the public ownership of bank dummy is *GOB_UO50*. This is the indirect public ownership dummy that equals one when the identified ultimate owner of more than 50 percent of the bank is the government. Variable definitions are given in table 1.

	All Banks					**Private Banks *GOB_UO50* = 0**			**Public Banks *GOB_UO50* = 1**		
Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**	**Mean**	**Std. Dev.**	**N**	**Mean**	**Std. Dev.**	**N**
gGDP	3.48	3.63	−17.73	26.17	23339	3.39	3.61	20661	4.12	3.73	2678
OutputGap	0.22	2.10	−11.02	13.33	12461	0.23	2.11	11335	0.13	2.00	1126
OutputTrend	−0.12	1.90	−15.15	9.40	23339	−0.13	1.91	20661	−0.07	1.82	2678
gLoan	12.00	26.03	−100.00	100.00	23339	11.95	26.59	20661	12.45	21.19	2678
gLoanCorp	6.63	34.98	−100.00	100.00	17759	6.46	35.33	15850	8.01	31.91	1909
L.Size	8.40	2.88	−4.43	18.86	23339	8.32	2.92	20661	9.02	2.44	2678
L.SizeRel	2.71	5.73	0.00	92.30	23339	2.62	5.79	20661	3.44	5.15	2678
L.gSizeRel	6.50	634.11	−97.54	95847.37	23339	2.75	96.09	20661	35.41	1852.90	2678
L.SizeMarket	2.89	5.45	0.00	48.30	23339	3.01	5.64	20661	2.03	3.56	2678
L.gSizeMarket	4.09	46.37	−81.48	1782.93	23339	4.19	47.79	20661	3.37	33.41	2678
L.CR4	0.70	0.11	0.47	1.00	23339	0.70	0.11	20661	0.71	0.11	2678
L.ChangeRatingLT	0.10	2.89	−31.00	18.00	23339	0.09	2.89	20661	0.20	2.89	2678
L.lnGDPperCapita	9.21	1.32	5.76	11.12	23339	9.27	1.28	20661	8.78	1.55	2678
L.Inflation	5.51	7.41	−24.25	115.52	23339	5.52	7.52	20661	5.45	6.57	2678
RealInterestRate	6.86	10.22	−35.31	93.92	23310	6.87	10.22	20470	6.78	10.26	2640
chLendingInterestRate	−0.68	4.54	−59.44	69.82	23339	−0.68	4.64	20661	−0.67	3.67	2678
gMMF	−3.13	44.10	−100.00	100.00	11062	−3.22	44.31	9588	−2.59	42.67	1474
gSTfunding	3.72	36.29	−100.00	100.00	9839	3.43	36.30	8836	6.25	36.16	1003
gLTfunding	3.44	33.95	−99.99	100.00	13468	2.88	34.56	11690	7.14	29.37	1778
gNonCoreRatio	−2.39	34.93	−99.99	100.00	19789	−2.37	35.41	17616	−2.61	30.71	2173
gLLPratio	−19.01	49.69	−99.99	100.00	11979	−19.15	49.84	10523	−18.00	48.59	1456

the unconsolidated ones to obtain the most disaggregated information, and when they publish their results with different closing dates, I use those that are closest to the end of the fourth quarter.[6]

Nevertheless, duplicated assets potentially remain if included in different balance sheets—for instance, after a merger[7]—or when banks are subsidiaries of others. This is a common issue in the Bankscope database, which does not allow to track the evolution of cross-ownership over time. But this is not of major concern here, as I do not focus on country aggregates of banking variables. When needed as control variables, I keep only consolidated publications of the top 20 banks to compute aggregate assets at the country level, so that I am more likely to capture the actual size of the banking sector.

I focus only on countries with at least two banks, since I sometimes have only a single pair of public/private banks for the same year. Additionally, I restrict the study to banks that are among the largest 100 banks ranked yearly by country[8] and drop banks with less than five observations, to prevent my data set from being excessively unbalanced.

Eventually, the sample size is further reduced as I use growth rates as well as lagged variables. I define growth rates above 100 percent as missing, except for asset size, so that I can approximately control for mergers and acquisitions that create spikes in growth rates.

I am left with a panel-stationary[9] data set including eighty-three countries over the 1990–2010 period.

---

[6]Some countries (such as Canada or Japan) usually publish their financial statements in March and have to be recoded as belonging to the year $t-1$. I discard releases made from April until September which cannot really be attributed to either year t or year $t-1$.

[7]I ran all regressions by excluding all banks that did not appear in my data set in 2008, which almost completely removes the risk of a bank merged in the 1990s or early 2000s of being still recorded as a separate entity in 2008. All results remain unchanged.

[8]This is not very restrictive, as I want to keep most public and privatized bank observations. Results are not sensitive to this threshold and remain unchanged if, for instance, I only focus on the top 20 banks.

[9]The Fisher stationarity statistic for panel data tests for the hypothesis that at least one series is stationary against the null of all series being non-stationary.

2.2 Public Ownership Definition

I use five data sources: Bankscope, the World Bank privatization database, the World Bank database of banking crises, the International Monetary Fund (IMF) systemic banking crises database, and the data set compiled by La Porta, Lopez-de-Silanes, and Shleifer (2002) in their seminal work. Table 3 summarizes the composition of the data set.

The benchmark for the construction of the public ownership dummies are three variables of government ownership of banks (GOB) from Bankscope. This database provides data on the intensity in the government-bank relation, namely banks directly owned by the government (as controlling shareholder, CSH) or possibly indirectly owned (ultimate owner, UO). The share of public ownership is also included: when more than 50 percent is owned by the government (my variables *GOB_CSH50* or *GOB_UO50*) or when more than 25 percent of the bank is owned by the government (my variable *GOB_UO25*). When compiling the different government ownership dummies, I focus only on public banks owned by the public authorities of the country in which they operate and I discard government-owned banks operating abroad. This is because I want to focus only on public banks that are likely to respond differently to the national economic cycle due to the involvement of the government. From the Bankscope data set, I obtain records for at most 280 public banks, possibly indirectly owned at the 25 percent threshold by the national public authorities.

But the Bankscope database does not provide bank ownership over time, so that the public ownership information in the raw data reflects the ownership structure at the date of the last update (in my data set, somewhere between 2007 and 2010, depending on the bank). Note that due to the large wave of privatizations in the 1980s and 1990s, banks that are not owned by the public authorities at the end of my sample may have been privatized earlier, perhaps still impacting their subsequent lending policies.

I therefore proxy for this time variation in government ownership of banks by matching individual banks with the record of privatizations of the World Bank[10] that covers privatization events of

[10]Banks from the World Bank privatization database are matched with the Bankscope database using either the current or previous name of the bank.

Table 3. Composition of the Panel of Banks

SavingsBank, InvestBank, RealEstBank, CommercialBank, and *GvtCreditInstit* are dummy variables for, respectively, savings banks, investment banks and trust corporations, real estate and mortgage banks, commercial and credit card banks, and finally government credit institutions. *Privatized* and *BeforePrivatized* are two dummy variables for banks privatized during the sample period (sometimes the first year available is the year of the privatization) and the years before the privatization took place. Variable *GOB_CSH50* is the direct public ownership dummy when the government is the controlling shareholder of more than 50 percent of a bank. Variables *GOB_UO50* and *GOB_UO25* are indirect public ownership dummies when the government is the ultimate owner of, respectively, more than 50 or 25 percent of a bank. *Foreign* is a dummy variable for banks ultimately owned by a foreign entity at a minimum of 25 percent. *NatCrisis* and *NatIn2008* are two dummy variables, respectively, for banks of countries that nationalized part of their banking system during a banking crisis and for banks nationalized over the 2008 systemic banking crisis. The precise definition of variables is given in table 1.

Variable	**Obs.**	**No. of Banks**	**No. of Countries**	**Percent**
SavingsBank	2226	311	30	9.54
InvestBank	1533	198	48	6.57
RealEstBank	867	128	25	3.71
CommercialBank	17213	2057	83	70.49
GvtCreditInstit	1500	158	51	6.43
Privatized	752	86	30	3.22
BeforePrivatized	246	49	22	1.05
GOB_CSH50	1821	244	58	7.80
GOB_UO50	2678	327	64	11.47
GOB_UO25	3049	366	68	13.06
Foreign	6150	763	81	26.35
NatCrisis	6874	721	18	29.45
NatIn2008	96	21	12	0.41
All	23339	2852	83	100

at least 1 million USD during the period 1988–2008. This method allows me to identify eighty-six additional government-owned banks in thirty countries[11] that were privatized during my reference period. Privatization events that took place before the first available observation in Bankscope are captured by bank fixed effects. However, some privatization events cannot be dealt with, if they concerned smaller deals or took the form of divestitures in which none of the privatized entities kept the name of the previous public bank. Another limitation is that I only know the date on which a privatization occurred, with the public authorities selling part of their shares for a certain amount; but I do not know the initial level of public ownership, which prevents me from computing the post-privatization share of public ownership. Therefore, I only consider the last round of privatization events of each bank as the cut-off date at which the bank is no longer considered public. Henceforth, when the ownership dummy signals the bank as being private, it has no more than 50 or 25 percent of public ownership. But when the ownership dummy signals the bank as being public only at the beginning of my sample, I cannot be sure that the public authorities owned more than a specific fraction of the bank. If my public bank dummies do not take into account all privatized banks, the bias should be towards a smaller difference in the lending cycle between what I consider as public and private banks.

Ideally, I would also like to capture the nationalization events in order to get a better proxy of the time variation of my public ownership dummies. However, such a record does not exist across countries, except for banks nationalized after the outbreak of the 2008 crisis, some of which are listed in the IMF database on systemic banking crises. Therefore, I can only track countries that nationalized some banks (which I am unable to identify precisely) during specific periods of stress. This is the relevant piece of information

[11] Out of 703 privatization episodes for financial institutions, I obtain 195 individual matches. A large number of privatization events are not matched, as the categories recorded are much broader than banks (financial services, insurance, industrial groups, pension funds, real estate, social security), and privatization of banks may have occurred before they started being recorded by Bankscope. Conversely, the number of banks matched is smaller than the number of individual matches, as several banks went through multiple waves of privatization over time.

for the purpose at hand, as banks nationalized during a banking crisis may introduce a selection bias in the public/private ownership dummy: public banks include the banks that once failed and had to be restructured, which probably limited their lending abilities and thus darkened the case for public banking. I account for bank nationalizations at the country level using two data sets: the World Bank database on banking crises, which reports countries where the state took over troubled financial institutions over the period 1980–2003,[12] and the nationalization-during-crisis dummy used by La Porta, Lopez-de-Silanes, and Shleifer (2002). Banks rescued but without transfer of ownership are not considered nationalized; hence, if they were able to lend more or reduce their lending activities less over the crisis, these banks that are coded as private would appear less procyclical, and the bias would go against the results presented here. However, the effect of banks rescued without ownership transfer is likely to be captured when controlling for the evolution of the country rating.

The data set includes at most 366 public banks in sixty-eight countries, of which 86 banks in thirty countries were privatized, out of a total of 2,852 distinct banks. Among the eighty-three countries I cover, sixty-five did not experience nationalizations during a crisis before 2008.

2.3 *Methodology*

2.3.1 *Baseline Specification*

I focus on the role of the economic cycle and ownership status in determining the evolution of credit distributed by banks (loan growth, *gLoan*[13]) by estimating the following model as a benchmark:

$$\begin{aligned} gLoan_{i,t} = {} & MacroShock_{c,t} \cdot \{\beta_1 + \beta_2 \cdot Pu_i + \beta_3 \cdot Sav_i + \beta_4 \cdot Est_i \\ & + \beta_5 \cdot Inv_i + \beta_6 \cdot For_i\} + \beta_7 \cdot Pu_i + \beta_8 \cdot Sav_i + \beta_9 \cdot Est_i \\ & + \beta_{10} \cdot Inv_i + \beta_{11} \cdot For_i + \beta_{12} \cdot \mathbf{X}_{i/c,t-1} + \upsilon_{i,t}, \qquad (1) \end{aligned}$$

[12] I use the "Comments" column of this database, which describes the evolution of each banking crisis and reports nationalizations as they occurred.

[13] The results are indifferent to choosing gross or net loan growth as the explained variable.

where i stands for the bank, t for the year, and c for the country. Pu (respectively, Sav, Est, Inv, For) is a dummy variable that takes the value 1 if the bank is considered public (respectively, savings, real estate, investment bank, or foreign).

I use several alternative variables to proxy for the economic cycle, which I here call $MacroShock$; as a benchmark, I use GDP growth,[14] but also the deviation from the HP-filtered output trend. Hence β_1 represents the systematic relationship between *private* bank loan growth and the cycle when the proxy for macro shocks increases by 1 percentage point, while $\beta_1 + \beta_2$ is the specific co-movement of *public* bank lending with macroeconomic fluctuations. I am interested in the sign and significance of β_2, which gives the additional effect on lending growth due to public ownership.

Moreover, to ensure that the cyclicality of public bank lending does not capture the distinction between domestic and foreign ownership, I need to include the foreign dummy[15] and its interaction with the macro shock. Failing to take the larger volatility of foreign bank lending into account would artificially increase the aggregate lending cyclicality of private banks and widen the gap with public bank lending fluctuations.

Likewise, in order not to confuse the effect of specific banking models with the ownership feature, I control for each bank type and its interaction with the macro shock variable. Commercial banks are taken as the benchmark, so that the dummy and the interaction term do not appear in the regression. It is worth noting that banks

---

[14]I use GDP growth rather than the growth rate of GDP per capita; the latter is useful if one is focused on development issues related to public banking, but I prefer the former, as I want the evolution over the cycle, in response to shocks: what matters is the aggregate size of bank lending in relation to the expansion of GDP, rather than the actual availability of loans to each individual and its interaction with individual wealth.

[15]The foreign ownership dummy is limited to the extent that it only reflects end-of-period ownership, as of 2007–10. Consequently, I might capture banks that were sold to a foreign institution and were not foreign at an earlier date, but this would only dilute the specific lending cyclicality properties of foreign banks; what really matters here is to capture away the foreign banks to avoid misinterpreting the impact of public banking.

classified by Bankscope as special government credit institutions[16] de facto have no private counterparts in their sub-category. As a robustness check, I consider only public and private commercial banks without special credit institutions.

2.3.2 Controls

I control for macroeconomic country-wide variables, banking-sector specificities, and individual bank features.

First, I control for country rating changes[17] over the previous year. My concern is to ensure that the interaction between public bailout and implicit guarantees does not blur the picture: an increase in the support of ailing banks by public authorities is likely to boost their lending, but as it increases the fiscal burden on the government, it may reduce the implicit guarantees enjoyed by private banks and thus increase the rate at which they refinance themselves. In turn, this would limit their lending abilities in the following period and induce them to lend more procyclically in the case of a bad shock. I also control for the lagged logarithm of GDP per capita in order to proxy for economic development, which might not be orthogonal to the use of public banking as a way of boosting lending, if one takes a development approach to public banking.[18] I also include lagged GDP growth, lagged inflation, the real interest rate, and the average change in national lending rate, which capture the evolution of the demand side in a specific country and the ability of banks to make profitable lending decisions. As a matter of fact, public ownership

[16]This group of banks includes major public banks, such as the Landesbanken in Germany or the Banques Cantonales in Switzerland, that are commercial/retail banks, or export-import banks in many countries providing corporate loans.

[17]S&P ratings and outlooks for long-term ratings in foreign currency are converted to a numerical scale from 1 (“D” and negative outlook) to 69 (“AAA” and positive outlook), so that a downgrade decreases the rating by several notches while a mere change in the outlook is equivalent to a one-notch decrease. However, a shortcoming of this approach is that the effect of a change in country ratings is linear and, as a result, the effect does not depend on the initial grade of the country.

[18]The alternative would be to consider indices of financial and institutional development, which are unlikely to be time varying and available for all countries. Also, some of those indices include government intervention in the banking sector as an input, which de facto makes them useless here. See Bertay, Demirgüç-Kunt, and Huizinga (2015) for a similar paper taking this route.

can be understood as a rent in a protected market, so that it should be distinguished from the overall macroeconomic conditions that provide more or less profit opportunities for the banking sector as a whole. And when required, I include crisis years and nationalizations in crisis dummies.

Second, I control for banking-sector specificities,[19] namely lagged banking concentration (concentration ratio of the top 4 banks) as well as previous period market size and its evolution over time. The level of competition within a banking sector is important, as banks tend to increase their leverage when the intensity of competition increases; also deeper markets can have access to cheaper financing sources, while smaller markets can have a stronger growth potential. In addition, by including the growth rate of market size, I can to some extent capture breaks in the reporting of bank balance sheets by Bankscope.

Third, I control for bank-specific balance sheet variables. I focus mainly on size variables[20] (the absolute size with the log of assets and the relative size with the business share of each bank) without retaining liquidity, capital positions, or profitability in the baseline, as these variables may actually reflect the difference between public and private banks. Including these controls would reduce the number of public banks in the data set that may not be subject to the same market disclosure rules, and would therefore restrict cyclical differences in lending growth to banks having similar balance sheet composition and similar profitability. On the contrary, I prefer in a second step to study the extent to which balance sheet composition impacts lending cyclicality differently for public or private banks. In addition, by controlling for the growth rate of the relative size of the bank, I intend to grasp post-merger situations, which are characterized by spikes in relative bank size. If mergers and acquisitions are procyclical, this would tend to increase the loan cyclicality of private banks more than that of public banks. When required, I include

[19]For market-wide aggregates, I use figures of the banking sector based on the same Bankscope data set but with only consolidated data, so that I am sure to avoid double-counting assets when working with the larger, unconsolidated, data set.

[20]There is some evidence that smaller banks invest more in the collection of “soft” information (Berger et al. 2005), which may induce more stable credit policies and less cyclical long-term relationships.

dummies for privatized banks (possibly before/after) and/or 2008–9 bank bailout packages.

2.3.3 Lending through the Cycle Regression

To analyze the behavior of public banks during the upswing or the downturn, I now distinguish between expansionary and recessionary phases as well as the intensity of the positive or negative shock. First, I cannot use the same reference point (e.g., positive or negative growth rates) across countries, or else I would blur the effects in a cross-country analysis that includes fast-growing developing countries and slow-growing developed countries. I can instead consider observations above or below the mean growth rate of GDP by country over the whole period, so that I have roughly the same number of observations above or below. But in this particular case I would implicitly assume that the correct country-specific reference point is time invariant, and the interpretation of the coefficient would be difficult. In fact, I would only observe the cyclicality of bank lending clustered by above/below mean GDP growth, but would not be able to say, for instance, that public banks reduced their loans less in the case of bad economic conditions.[21]

Ideally, one would rather focus on the positive or negative deviation from the country-specific potential output.[22] But this output gap is only available for OECD member states. Instead, to keep the largest cross-section, I use the deviation from the HP-filtered output trend,[23] so that the expansionary phase corresponds to GDP growing faster than its trend.

[21] Above/below country average growth rates might combine both positive and negative growth rates so that sign interpretation would not be possible. Hence, results are not reported but support the results presented thereafter, with government-owned banks featuring less cyclical lending mostly in the below-average cluster.

[22] Potential output is defined as the level of output that an economy can in principle produce at a constant inflation rate, in the absence of temporary shocks. It depends on the capital stock, the potential labor force, the non-accelerating inflation rate of unemployment (NAIRU), and the level of labor efficiency.

[23] The output trend is calculated using a Hodrick-Prescott filter with smoothing parameter of 6.25 on the data set of yearly GDP from 1970 to 2010, as suggested by Ravn and Uhlig (2002).

Thus, I estimate equation (1), but by considering positive or negative macroeconomic shocks (β_2 is broken down into $\beta_{2,1}$ and $\beta_{2,2}$) as well as square terms (the α terms) to see whether the impact intensifies when the shock is more or less positive or negative. Pos (Neg) is a dummy variable which takes the value 1 if the variable $MacroShock$ is positive (negative).

$$gLoan_{i,t} = MacroShock_{c,t} \cdot \{\beta_1 + \beta_{21} \cdot Pu_i \cdot Pos_{c,t} + \beta_{22} \cdot Pu_i \cdot Neg_{c,t} + \ldots\} + MacroShock^2_{c,t} \cdot \{\alpha_1 + \alpha_{21} \cdot Pu_i \cdot Pos_{c,t} + \alpha_{22} \cdot Pu_i \cdot Neg_{c,t}\} + \alpha_3 \cdot Pos_{c,t} + \cdots + \upsilon_{i,t} \quad (2)$$

Alternatively, I test the asymmetric behavior of public banks over the business cycle and the differential effect depending on the magnitude of the shock by splitting the sample into four categories (Cat). Large (small) positive shocks correspond to the observations above (below) the median positive shocks for each country, and likewise for large and small negative shocks. Hence, the estimated equation is

$$gLoan_{i,t} = MacroShock_{c,t} \cdot \left\{\beta_1 + \sum_{Cat} \beta_{Cat} \cdot Pu_i \cdot Cat_{c,t} + \ldots\right\} + \sum_{Cat} \mu_{Cat} \cdot Cat_{c,t} + \cdots + \upsilon_{i,t}. \quad (3)$$

2.3.4 Estimation Choice

As a baseline, I use the within estimator[24] and I consider the following structure for the error term:

$$\upsilon_{i,t} = \alpha_i + \alpha_c + \alpha_t + \alpha_{c,t} + \epsilon_{i,t}.$$

When using the within estimator, time-invariant bank (α_i) and country (α_c) fixed effects are taken care of while controlling for the time trend. When the panel is reduced to 1999–2010 so that it is better balanced, the interaction between country and year dummies ($\alpha_{c,t}$) is included; then I can compare public and private bank

[24] As the results of Haussman tests suggest, I reject the hypothesis of uncorrelated individual effects.

lending variations within each country for each year. As a result of my specification, I discard all country-specific and time-invariant institutional arrangements.

To make sure the results are not driven by the over-representation of some countries, which is a common problem in Bankscope, I give each country an equal weight.[25]

3. Public Bank Lending Is Less Cyclical than Private Bank Lending

3.1 Graphical Analysis

Figure 1 displays the evolution in bank loan growth in percentage points associated with a 1 percent change in GDP, using an eight-year rolling window.[26] The graph on the left pictures a lending boom by private banks where each additional percentage point of GDP tends to be associated with at least a 1 percent growth in gross loans. As far as public banks are concerned, the graph on the right illustrates acyclical loan growth, with a deviation associated with a 1 percent increase in GDP not significantly different from zero, at least until 2004. But from 2004 onwards, on average, public bank lending starts to be procyclical, even if less procyclical than private banks, suggesting that they both increased their lending to benefit from the boom and/or that, when hit by the crisis, they had to readjust their lending policy.

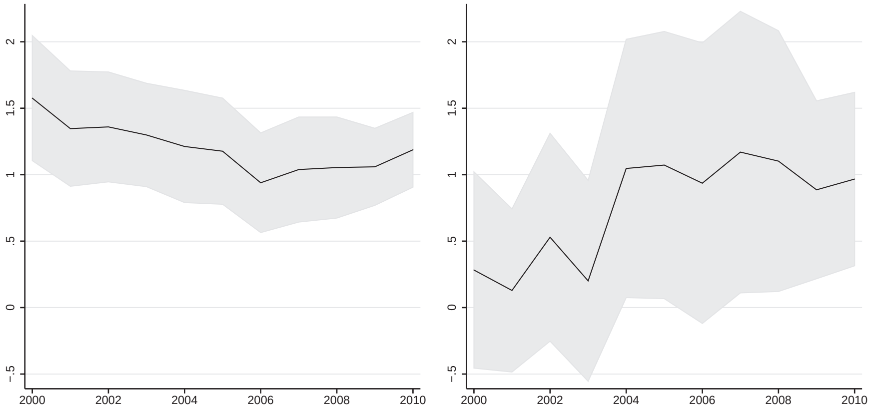
3.2 Regression Analysis

The main results are presented in table 4. Public bank lending appears to be significantly less cyclical than private bank lending, whether public ownership is direct (columns 1 and 2) or not (columns 3–6).

[25] For that purpose, I use the frequency weights option which is directly provided by Stata; thus, the weight of an observation is inversely proportional to the number of observations within a given country. In other words, an observation in an over-represented country like Germany or the United States will be assigned a smaller importance, so that ultimately each country has the same contribution to the average effect.

[26] The graph is similar whether I keep or drop countries with nationalizations during a crisis and banks nationalized over the 2008–9 financial crisis.

Figure 1. Evolution of Lending Cyclicality for Private (Left) and Public (Right) Banks



Notes: For private (respectively, public) banks, the estimates correspond to the coefficient β_1 (respectively, $\beta_1 + \beta_2$) of equation (1). Each point of the graph reports the estimates of the benchmark model, with a rolling window over the past eight years. Public ownership is defined as ultimate ownership (*GOB_UO50*), that is to say the indirect public ownership of more than 50 percent of a bank. The solid line is the movement of loan growth (in percentage points) associated with a 1 percent change of GDP. The shaded area displays the 95 percent confidence bands.

Nevertheless, two complementary remarks call for a more careful look at ownership change. First, some ailing banks may have been nationalized during a crisis, either after 2008 or since 1970, precisely to avoid a lending freeze, which could be captured by the public bank dummy and could artificially increase the difference in lending cyclicality. This effect seems to be present for banks directly controlled by the government. As a matter of fact, when I remove banks nationalized during the 2008 crisis and drop the countries that nationalized banks during a banking crisis between 1970 and 2004, the lower cyclicality of public bank lending is somewhat weaker (column 2).

Second, failing private banks nationalized during a crisis are unlikely to feature countercyclical lending; hence, this correlation between public ownership and asset restructuring blurs the possible "lending against the wind" ability of public banks. And this effect seems to prevail for indirect public ownership of banks. The gap

Table 4. Main Results on Lending Cyclicality, 1990–2010

Results of the loan growth equation (1) using the within estimator. The left-side variable is total gross loan growth. The proxy of the macroeconomic shock is GDP growth. Direct public ownership of more than 50% of a bank means that the government is the controlling shareholder (*GOB_CSH50*). Indirect public ownership of more than 50 or 25% of a bank means the government is the ultimate owner (*GOB_UO50* or *GOB_UO25*). The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. Other covariates include a constant term, the public bank dummy, the lag market size, the lag concentration ratio, the lag inflation, the lag log of GDP per capita, and the change in lending interest rate. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Public Ownership Dummy Definition Dependent Variable	**Direct, >50% Loan Growth**		**Indirect, >50% Loan Growth**		**Indirect, >25% Loan Growth**	
Macro Shock	**GDP Growth**		**GDP Growth**		**GDP Growth**	
Macro Shock*Public Dummy	−0.811***	−0.738***	−0.416	−0.895***	−0.371	−0.725***
	(0.197)	(0.258)	(0.309)	(0.281)	(0.269)	(0.256)
Macro Shock*Foreign Dummy	0.183	0.288**	0.195	0.201	0.188	0.186
	(0.112)	(0.139)	(0.123)	(0.143)	(0.124)	(0.150)
Macro Shock*Savings Bank Dummy	0.550	0.657	0.610	0.644	0.596	0.615
	(0.499)	(0.567)	(0.515)	(0.581)	(0.517)	(0.564)
Macro Shock*Investment Bank	0.156	0.299	0.127	0.263	0.134	0.295
	(0.415)	(0.530)	(0.423)	(0.522)	(0.420)	(0.501)
Macro Shock*Real Estate Bank	0.724*	0.791	0.716*	0.815	0.707*	0.786
	(0.412)	(0.577)	(0.419)	(0.586)	(0.419)	(0.585)
GDP Growth	1.158***	0.829***	1.152***	0.929***	1.156***	0.936***
	(0.134)	(0.164)	(0.125)	(0.174)	(0.127)	(0.185)
Lag GDP Growth	0.570***	0.558***	0.569***	0.552***	0.567***	0.546***
	(0.144)	(0.161)	(0.142)	(0.160)	(0.141)	(0.160)
Lag Log of Bank Asset	−4.378***	−4.513**	−4.372***	−4.554**	−4.375***	−4.548**
	(1.475)	(1.886)	(1.473)	(1.890)	(1.471)	(1.883)
Lag Change Long-Term Rating	0.571***	0.899***	0.572***	0.894***	0.570***	0.898***
	(0.175)	(0.239)	(0.174)	(0.239)	(0.175)	(0.239)

(continued)

Table 4. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Public Ownership Dummy Definition Dependent Variable	**Direct, >50% Loan Growth**		**Indirect, >50% Loan Growth**		**Indirect, >25% Loan Growth**	
Macro Shock	**GDP Growth**		**GDP Growth**		**GDP Growth**	
Real Interest Rate	−0.167*	−0.182*	−0.167*	−0.181*	−0.168*	−0.182*
	(0.095)	(0.097)	(0.094)	(0.097)	(0.094)	(0.097)
Lag Bank Relative Size	−0.343**	−0.428***	−0.341**	−0.431***	−0.339**	−0.423***
	(0.148)	(0.142)	(0.149)	(0.143)	(0.147)	(0.140)
Growth of Bank Relative Size	0.075*	0.117*	0.076*	0.118*	0.076*	0.117*
	(0.040)	(0.063)	(0.040)	(0.063)	(0.040)	(0.063)
Lag of Growth of Bank Relative Size	0.027**	0.042**	0.028***	0.043**	0.028**	0.042**
	(0.011)	(0.019)	(0.011)	(0.018)	(0.011)	(0.018)
Market Size Growth	0.019	0.071**	0.019	0.071**	0.019	0.071**
	(0.025)	(0.033)	(0.025)	(0.033)	(0.025)	(0.033)
Lag Market Size Growth	0.038***	0.019	0.038***	0.020	0.038***	0.020
	(0.010)	(0.012)	(0.010)	(0.012)	(0.010)	(0.012)
Macro Shock + Macro Shock*Public Dummy	.347	.091	.736**	.034	.785***	.21
	(.247)	(.334)	(.345)	(.317)	(.303)	(.281)
R^2	0.142	0.148	0.142	0.148	0.142	0.148
No. Countries	83	65	83	65	83	65
No. Public Bank Observations	2067	1667	2907	2310	3231	2568
No. Private Bank Observations	21272	14773	20432	14130	20108	13872
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Interaction Fixed Effects	No	No	No	No	No	No
Drop Nationalization in Crisis	No	Yes	No	Yes	No	Yes
Drop Nationalizations 2008–10	No	Yes	No	Yes	No	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

between public and private banks in terms of lending fluctuations is significantly different from zero only when I drop nationalizations during a banking crisis (columns 4 and 6). In short, by excluding nationalizations, when I combine the coefficients to obtain the total effect, public bank lending becomes acyclical.

In addition, the feedback loop of reduced implicit public guarantees of private banks as a result of costly bank bailouts does indeed limit the ability of private banks to issue new loans; this specific effect, captured by the change in long-term country rating, is such that a downgrade during the previous period reduces private bank loan growth.

Moreover, foreign-owned banks tend to feature a somewhat stronger reaction to macroeconomic fluctuations, probably due to their ability to attract international flows in the expansion phase and to reallocate funds in areas with less correlated business cycles in case of downturn.

3.3 Robustness Checks

I now display alternative strategies to identify the effect of public bank ownership on lending cyclicality, first using different specifications, then a sub-sample of commercial banks only, and last a sub-sample of countries that privatized part of their public banking sector.

3.3.1 Alternative Specifications

A set of robustness checks is displayed in table 5. First, regression 1 includes the lag dependant variable (lagged loan growth), which turns out not to be significant, as I already control for variables such as the lag of GDP growth or the lag of absolute and relative asset size.

Second, in regression 2, I use the subset of corporate loans, although it reduces the sample size by one-fourth. The lower lending cyclicality could be driven by forced loans to the government, not business or housing loans, but this is no longer an issue when restricted to corporate loans.

Third, I use the output gap as an alternative metric for the size of the macroeconomic shock with consistent results (column 3).

Table 5. Robustness Check: Alternative Specifications

Results of the loan growth equation (1). The left-side variable is total gross loan growth (*gLoan*) or corporate loan growth (*gLoanCorp*). The proxy of the macroeconomic shock is GDP growth or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. Estimated either using the within estimator or a GMM specification using the forward orthogonal deviation transform as well as collapsed instruments. When using the GMM estimation with the xtabond2 command (that does not report R^2), the sample is reduced to countries with at least one public bank after 1997; all available lags are used as instrument of the macro shock. Country-year interaction fixed effects require a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. The usual set of covariates is used but not reported. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Sample **Estimator** **Dependent Variable**	**All** **Within** ***gLoan***	**All** **Within** ***gLoanCorp***	**All** **Within** ***gLoan***	**Restricted** **GMM** ***gLoan***	**Since 1999** **Within** ***gLoan***	
Macro Shock	**GDP Growth**	**GDP Growth**	**Output Gap**	**GDP Growth**	**GDP Growth**	**Output Gap**
GDP Growth	0.933***	0.613**	1.007***	−1.250		
	(0.173)	(0.300)	(0.172)	(1.644)		
Lag GDP Growth	0.567***	0.976***	0.591***			
	(0.149)	(0.210)	(0.160)			
Output Gap			−0.219			
			(0.328)			
Lag Dependent Variable	−0.011					
	(0.024)					
Macro Shock*Public Dummy	−0.903***	−1.381***	−0.805**	−2.681**	−0.627**	−0.657**
	(0.275)	(0.487)	(0.342)	(1.226)	(0.298)	(0.324)
Macro Shock*Foreign Dummy	0.202	0.349	0.338	0.411	0.175	0.412
	(0.144)	(0.242)	(0.347)	(0.779)	(0.146)	(0.266)

(continued)

Table 5. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	**All**	**All**	**All**	**Restricted**	**Since 1999**	
Estimator	**Within**	**Within**	**Within**	**GMM**	**Within**	
Dependent Variable	***gLoan***	***gLoanCorp***	***gLoan***	***gLoan***	***gLoan***	
Macro Shock	**GDP Growth**	**GDP Growth**	**Output Gap**	**GDP Growth**	**GDP Growth**	**Output Gap**
Macro Shock*Savings Bank	0.645	1.638***	0.012	2.216	0.521	−0.302
	(0.584)	(0.344)	(0.932)	(1.402)	(0.596)	(0.961)
Macro Shock*Investment Bank	0.257	0.960**	−0.326	0.978	0.248	−0.253
	(0.519)	(0.433)	(1.055)	(0.964)	(0.288)	(0.804)
Macro Shock*Real Estate Bank	0.808	2.334***	0.945	1.873	0.061	0.547
	(0.588)	(0.511)	(0.975)	(1.133)	(0.379)	(0.844)
R^2	0.148	0.065	0.147		0.262	0.261
No. Countries	65	76	65	60	64	64
No. Public Bank Obs.	2310	1484	2310	2656	1945	1945
No. Private Bank Obs.	14130	16604	14130	14347	10431	10431
Bank and Country Fixed Effects	Yes	Yes	Yes	No	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Fixed Effects	No	No	No	No	Yes	Yes
Drop Nationalization in Crisis	Yes	No	Yes	No	Yes	Yes
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes	Yes	Yes
First-Order AR Test				0		
Second-Order AR Test				.970		
Hansen Test				.302		

*p < 0.10, **p < 0.05, ***p < 0.01.

Fourth, regression 4 estimates a system-GMM specification[27] in order to be able to instrument GDP growth and all relevant interaction terms that include the macroeconomic shock.[28] Even though I am mostly interested in the co-movement of bank lending with economic fluctuations, I want to make sure that my parameter estimation does not suffer from the possibility of reverse causality, whereby loan growth fosters current GDP growth or vice versa. Consistent results are obtained.[29]

Last, in order to fully account for macroeconomic conditions at the country level, I include country-year fixed effects, at the cost of a more balanced sample starting in 1999 (columns 5 and 6). Thus all time-varying country-specific factors are netted out; that is to say, I compare public and private bank lending within the same country for the same year.

3.3.2 Sub-Sample of Commercial Banks Only

At the cost of a smaller set of public banks, instead of controlling for banks' business models as in the benchmark case, I can compare loan growth by public versus private banks with the same business model so that results are less likely to be driven by the heterogeneity in

[27] I use the xtabond2 command in Stata which allows me, first, to limit the number of missing observations by using the forward orthogonal deviation transform instead of the first-difference transformation, and second, to use the collapsed option in order to avoid the proliferation of instruments, as I am using all available lags as internal instruments. Moreover, I reduce my data set to countries with at least one public bank in order to avoid estimation problems when a dummy, here the public bank ownership dummy, has only a limited number of ones (Roodman 2009). In addition, in order to include country clustered standard errors, I need a more balanced data set, and for that reason I drop the years before 1997, for which I have fewer observations. Last, when several lags were used in the benchmark within regression, the additional lags are removed from the GMM, as the variables are precisely instrumented by their lags.

[28] Nevertheless, my focus here is not to instrument the public ownership dummy as in Bertay, Demirgüç-Kunt, and Huizinga (2015), which is a slow and rarely moving dummy unlikely to be well instrumented; I control instead for nationalizations in crisis.

[29] It successfully passes the Hansen J-statistic and difference-in-Hansen statistic tests. The former tests for the joint validity of all the internal instruments and is robust to heteroskedasticity; the latter tests for the validity of the lagged loan growth, GDP growth, and relevant interaction terms as instruments for the transformed equation and their first differences as instruments in the level equation.

corporate governance structures. Table 6 displays results restricted to the sub-sample of commercial banks for countries with at least one pair of public/private banks for some years. I am left with 111 public commercial banks for indirect public control at the 50 percent threshold.

When restricted to the 1999–2010 period to get a more balanced coverage, I can even compare public commercial banks with privately owned commercial banks of the same country in the same year (column 2), while column 1 uses more observations but instead captures the time variation in country-wide variables using a set of macro controls.

The same lower sensitivity of public bank lending is obtained if I now consider the output gap as an alternative proxy for macroeconomic shocks (columns 3 and 4). Last, it is interesting to note that only the subset of public commercial banks in high-income countries is less sensitive to macroeconomic shocks (GDP growth or output gap) once nationalizations during crises are taken into account and all the country-specific time variation is netted out (columns 5 and 6).

3.3.3 Before and After Privatization Events

I now make use of the time variation in my definition of public bank dummies: I focus on the same bank in a given country before and after the round of privatization[30] compared with the evolution of the banks that remained private or public during the whole period. Even if I ignore the magnitude of public ownership before the privatization event,[31] these events correspond to a dilution of the intensity of the public ownership of the bank which should be associated with a change in lending variations if bank ownership matters.

Results are displayed in table 7. When restricted to the thirty countries in which the eighty-six privatization events occurred, I observe that privatized banks are less cyclical before their privatization, whether the macroeconomic shock is proxied by GDP growth

[30]Whether I consider the largest or the latest privatization event in the case of multiple rounds of privatization, results are very similar.

[31]After the privatization event, I know by construction that the bank is not public if it is still in my database in 2008–10. If the bank drops out of my data set before, I also ignore the magnitude of the public ownership for the years after the last privatization round.

Table 6. Robustness Check: Commercial Banks Only

The sample is restricted to countries with at least one public bank at the 25% ownership threshold and to commercial banks only (narrowly defined as commercial and credit card banks, excluding specialized government credit institutions). The table reports results of the loan growth equation (1) using the within estimator. The left-side variable is total gross loan growth. The proxy of the macroeconomic shock is GDP growth or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. Other covariates include a constant term and the public bank dummy, the real interest rate, the lag market size, the lag market size growth, and the lag inflation. Country-year interaction fixed effects require a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	**Only Countries with Public Banks**		**Only Countries with Public Banks**		**High-Income Countries**	
Time Span	**All**	**Since 1999**	**All**	**Since 1999**	**Since 1999**	
Dependent Variable	**Loan Growth**		**Loan Growth**		**Loan Growth**	
Macro Shock	**GDP Growth**		**Output Gap**		**GDP Growth**	**Output Gap**
Macro Shock*Public Dummy	−0.868***	−0.886**	−1.404**	−1.061*	−2.753***	−3.274**
	(0.306)	(0.364)	(0.554)	(0.610)	(0.980)	(1.260)
Macro Shock*Foreign Dummy	0.040	−0.049	0.072	0.273	0.120	−1.086
	(0.161)	(0.114)	(0.371)	(0.309)	(0.262)	(0.667)
GDP Growth	1.091***		0.784***			
	(0.175)		(0.273)			
Lag GDP Growth	0.488***		0.381***			
	(0.112)		(0.134)			
Output Gap			0.726			
			(0.453)			
Lag Log of Bank Asset	−3.855**	−5.628**	−4.025**	−5.661**	5.920***	5.905***
	(1.696)	(2.535)	(1.667)	(2.511)	(2.011)	(1.921)

(continued)

Table 6. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	**Only Countries with Public Banks**		**Only Countries with Public Banks**		**High-Income Countries**	
Time Span	**All**	**Since 1999**	**All**	**Since 1999**	**Since 1999**	
Dependent Variable	**Loan Growth**		**Loan Growth**		**Loan Growth**	
Macro Shock	**GDP Growth**		**Output Gap**		**GDP Growth**	**Output Gap**
Lag Change Long-Term Rating	0.854***		0.893***			
	(0.170)		(0.178)			
Lag Bank Relative Size	−0.243	−0.637*	−0.214	−0.584	−0.705*	−0.698*
	(0.177)	(0.357)	(0.174)	(0.353)	(0.369)	(0.368)
Growth of Bank Relative Size	0.373***	0.410***	0.374***	0.410***	0.653***	0.654***
	(0.060)	(0.098)	(0.060)	(0.097)	(0.073)	(0.073)
Lag of Growth of Bank Relative Size	0.090***	0.087***	0.090***	0.087***	0.062*	0.063*
	(0.023)	(0.029)	(0.023)	(0.029)	(0.031)	(0.031)
Market Size Growth	0.140***		0.139***			
	(0.044)		(0.044)			
Lag Log of GDP per Capita	23.128*		20.548*			
	(11.464)		(11.020)			
Change Lending Interest Rate	−0.458*		−0.498**			
	(0.228)		(0.235)			
R^2	0.283	0.399	0.283	0.399	0.438	0.438
No. Countries	40	40	40	40	29	29
No. Public Bank Obs.	983	855	983	855	131	131
No. Private Bank Obs.	8261	6423	8261	6423	3169	3169
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Fixed Effects	No	Yes	No	Yes	Yes	Yes
Drop Nationalization in Crisis	Yes	Yes	Yes	Yes	Yes	Yes
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes	Yes	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

Table 7. Robustness Check: Before/After Privatization

The estimation sample is limited to the thirty countries where privatizations took place over the sample time span 1990–2010. Results of the loan growth equation (1) using the within estimator. The left-side variable is total gross loan growth. The proxy of the macroeconomic shock is GDP growth or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. The additional effect of being publicly owned before the privatization on the co-movement between lending growth and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the years before privatization dummy. Other covariates include a constant term, the public bank dummy, the real interest rate, the lag bank relative size, the lag inflation, the lag log of GDP per capita, and the change in lending interest rate. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)
Sample	**Only Countries with Privatized Banks**		**Only Countries with Privatized Banks**	
Bank Type	**All**		**Commercial**	
Dependent Variable	**Loan Growth**		**Loan Growth**	
Macro Shock	**GDP Growth**	**Output Gap**	**GDP Growth**	**Output Gap**
Macro Shock*Public Dummy	0.039	−0.029	0.551	0.783
	(0.444)	(0.465)	(0.723)	(1.283)
Macro Shock*Foreign Dummy	0.143	0.173	0.097	0.235
	(0.183)	(0.201)	(0.183)	(0.196)
Macro Shock*Before Privatization Dummy	−1.492*	−3.188**	−1.710**	−4.175**
	(0.749)	(1.457)	(0.800)	(1.847)
Macro Shock*Savings Bank Dummy	1.239***	1.068***		
	(0.297)	(0.324)		
Macro Shock*Investment Bank Dummy	−0.398	0.104		
	(0.274)	(0.422)		
Macro Shock*Real Estate Bank Dummy	1.019**	1.690*		
	(0.425)	(0.909)		
GDP Growth	1.359***	1.623***	1.359***	1.555***
	(0.254)	(0.314)	(0.273)	(0.328)
Lag GDP Growth	0.237**	0.330**	0.189	0.258*
	(0.113)	(0.124)	(0.129)	(0.129)
Output Gap		−0.534		−0.384
		(0.481)		(0.564)
Lag Log of Bank Asset	−4.878**	−4.790**	−4.997**	−4.924**
	(1.845)	(1.756)	(2.046)	(1.962)

(continued)

Table 7. (Continued)

	(1)	(2)	(3)	(4)
Sample	**Only Countries with Privatized Banks**		**Only Countries with Privatized Banks**	
Bank Type	**All**		**Commercial**	
Dependent Variable	**Loan Growth**		**Loan Growth**	
Macro Shock	**GDP Growth**	**Output Gap**	**GDP Growth**	**Output Gap**
Lag Change Long-Term Rating	0.933***	0.929***	0.811***	0.794***
	(0.296)	(0.291)	(0.276)	(0.270)
Lag Bank Relative Size	−0.190	−0.190	−0.117	−0.128
	(0.289)	(0.275)	(0.314)	(0.281)
Growth of Bank Relative Size	0.231***	0.231***	0.219***	0.220***
	(0.049)	(0.049)	(0.048)	(0.048)
Lag of Growth of Bank Relative Size	0.036*	0.036*	0.034	0.033
	(0.018)	(0.018)	(0.020)	(0.020)
Lag Market Size	0.573*	0.603**	0.655*	0.679*
	(0.292)	(0.276)	(0.366)	(0.358)
Market Size Growth	0.062*	0.062*	0.051	0.051
	(0.035)	(0.035)	(0.033)	(0.033)
Lag Market Size Growth	0.035**	0.035**	0.030	0.030*
	(0.017)	(0.016)	(0.018)	(0.017)
Lag Concentration Ratio	36.351*	35.025*	46.500**	44.930**
	(18.027)	(17.977)	(19.501)	(20.044)
R^2	0.240	0.239	0.242	0.242
No. Countries	30	30	30	30
No. Public Bank Obs.	1209	1209	581	581
No. Private Bank Obs.	7333	7333	6367	6367
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Country*Year Interaction Fixed Effects	No	No	No	No
Drop Nationalization in Crisis	No	No	No	No
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

(column 1) or by the output gap (column 2). This result is robust to the profile of the buyer of the stakes relinquished by the government or to a placebo analysis concerning the year of privatization.[32]

The result remains unchanged if I focus only on privatized commercial banks before and after the last wave of privatization (columns 3 and 4).

4. The Lower Lending Cyclicality of Public Banks Is Heterogeneous

4.1 Heterogeneity across the Stages of the Business Cycle

I now concentrate on the evolution of public bank lending over the stages of the business cycle. Thus I investigate the extent to which the lower cyclicality of public bank lending occurs mainly in reaction to negative shocks, when additional lending is particularly needed. Table 8 displays the results.

First, this asymmetric pattern can be tested using square terms for the negative macro shock. Column 1 shows that public banks reduce their lending less after a negative shock. But when the output deviates further from its trend, this effect weakens: the tendency of direct public ownership of banks to favor lending against the wind decreases when the economy deteriorates.

Second, I distinguish four categories, namely large and small, positive and negative macro shocks, defined as deviation from the output trend. I observe that public banks reduce significantly less their lending in the case of small negative shocks compared with similar private banks, whether countries with bank nationalizations are included or not (columns 2 and 4). But public banks fail to absorb larger negative shocks. As expected, when including bank nationalizations during a crisis, public banks cannot smooth credit relative to private banks in the case of a large negative macro shock (column 2). But even after dropping countries that experienced bank

[32] Regardless of who bought the stakes relinquished by the government (national or foreign block holding after privatizations), I find no additional effect. Also, when I do a placebo analysis, results do not vary if I take the year $t-1$ as the year of the privatization, but results are no longer significant when I take $t+1$.

Table 8. Heterogeneous Lending Cyclicality across Stages of the Business Cycle

The left-side variable is total gross loan growth. The proxy of the macroeconomic shock is the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. With two buckets, positive or negative macro shocks, equation (2) is estimated using the within estimator. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks during a crisis is captured by the sum of the linear and square interaction between the proxy for the negative macro shock and the public ownership dummy. With four categories, large or small, positive or negative macro shocks, equation (3) is estimated using the within estimator. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks when the macro shock is in one of the four categories (large or small positive or negative macro shock) is captured by the interaction between the proxy for the macro shock, the dummy for the category of the shock, and the public ownership dummy. Country-year interaction fixed effects require a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. The usual set of covariates is used but not reported. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)
Sample **Dependent Variable**	**All** **Loan Growth**				**Since 1999** **Loan Growth**	
Output Gap	−0.528*	−0.333	0.009	0.510	−0.934*	2.634***
	(0.303)	(0.366)	(0.417)	(0.519)	(0.486)	(0.331)
GDP Growth	1.382***	1.448***	1.007***	1.007***	0.099	0.979***
	(0.184)	(0.203)	(0.188)	(0.182)	(0.222)	(0.255)
Positive Output Gap*Public Dummy	−0.700		−1.618			
	(1.075)		(1.564)			
Negative Output Gap*Public Dummy	−2.633***		−1.553			
	(0.935)		(1.625)			
(Positive Output Gap)^2*Public Dummy	0.268		0.535			
	(0.226)		(0.373)			
(Negative Output Gap)^2*Public Dummy	−0.233***		0.025			
	(0.068)		(0.201)			

(continued)

Table 8. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)
Sample	**All**				**Since 1999**	
Dependent Variable	**Loan Growth**				**Loan Growth**	
Large Positive Output Gap*Public Dummy		0.321		1.172	0.240	1.620*
		(0.564)		(0.791)	(0.629)	(0.953)
Small Positive Output Gap*Public Dummy		−0.881		−2.720	3.445	2.631
		(2.133)		(3.678)	(2.075)	(3.881)
Large Negative Output Gap*Public Dummy		−0.467		−1.961**	−0.341	−2.088**
		(0.819)		(0.912)	(0.843)	(0.893)
Small Negative Output Gap*Public Dummy		−6.442**		−11.537***	−7.477**	−13.352***
		(2.706)		(3.602)	(3.330)	(4.788)
R^2	0.143	0.137	0.148	0.146	0.253	0.263
No. Countries	83	83	65	65	82	64
No. Public Bank Observations	20432	20432	14130	14130	15093	10431
No. Private Bank Observations	2907	2907	2310	2310	2456	1945
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Interaction Fixed Effects	No	No	No	No	Yes	Yes
Drop Nationalization in Crisis	No	No	Yes	Yes	No	Yes
Drop Nationalizations 2008–10	No	No	Yes	Yes	No	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

nationalizations during a crisis, the ability of public banks to absorb negative shocks is significantly reduced during periods of large output losses compared with its trend (column 4). Conversely, in the case of a positive macro shock with a GDP above its trend, public banks do not show a different pattern in the variation of their lending compared with the other banks. With a more balanced data set, the same results survive the inclusion of country-year interaction dummies, so that all time-varying country-specific effects are captured out (columns 5 and 6).

4.2 Heterogeneity across the Stages of Economic Development

I now turn to the interaction between ownership and lending cyclicality and economic development, in order to assess the extent to which the development view of public banking in the long run can be reconciled with an analysis of short-term variations. I split my data set into three sub-groups—low-, middle-, and high-income countries—roughly following the classification of the World Bank.[33] Table 9 displays the results of this operation.

The middle-income group is the one closest to the aggregate results presented above, with lower lending cyclicality of public banking, whether I consider GDP growth or the output gap as a proxy for macroeconomic shocks with or without country-year interaction dummies (columns 5 and 6). This lower cyclicality of public bank lending is especially significant in the case of a negative shock but at a decreasing pace as the size of the negative shock increases (column 7).

The high-income group also tends to show a lower lending cyclicality of public bank lending[34] (column 9, but this does not survive the inclusion of country-year effects in column 10), but this may be driven rather by a slower expansion of the activities of public bank

[33]Low-income countries are defined as countries with GDP per capita below 4,000 USD and high-income countries above 12,000 USD; if some countries have observations both above and below the threshold, they are included in the upper group. Compared with the grouping of the World Bank, the low-income group here corresponds to the low- and middle-low income groups of the World Bank.

[34]This is particularly the case for commercial banks, as shown in table 6, columns 5 and 6.

Table 9. Heterogeneous Lending Cyclicality across Stages of Economic Development

The sub-sample of countries by level of development roughly follows the classification of the World Bank. The left-side variable is total gross loan growth. The proxy of the macroeconomic shock is GDP growth (*gGDP*) or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. When looking at the homogeneous reaction across the business cycle, equation (1) is estimated using the within estimator. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. With two buckets, positive or negative macro shocks, equation (2) is estimated using the within estimator. The additional effect of being publicly owned on the co-movement between lending growth and macroeconomic shocks during a crisis is captured by the sum of the linear and square interaction between the proxy for the negative macro shock and the public ownership dummy. The usual set of covariates is used but not reported. Country-year interaction fixed effects require a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sample	**Low-Income Countries**				**Middle-Income Countries**				**High-Income Countries**			
Dependent Variable	**Loan Growth**				**Loan Growth**				**Loan Growth**			
Macro Shock	**GDP Growth**	**Output Gap**			**GDP Growth**	**Output Gap**			**GDP Growth**	**Output Gap**		
Output Gap			2.993	3.088			−1.127	−1.554			0.477	1.623
			(1.030)	(0.256)			(0.352)	(0.906)			(0.489)	(0.460)
GDP Growth	0.007	−1.196	−1.484	−0.403	0.933	2.007	1.466	0.900	0.787	0.484	0.698	−1.648
	(0.334)	(0.101)	(0.580)	(0.100)	(0.404)	(0.255)	(0.289)	(0.439)	(0.218)	(0.127)	(0.257)	(0.334)
Macro Shock* Public Dummy	−0.222	0.334			−0.869	−1.074			−1.672	0.245		
	(0.250)	(0.321)			(0.435)	(0.474)			(0.595)	(0.775)		
Positive Macro Shock*Public Dummy			−3.640	−3.543			1.260	2.587			−7.315	−5.183
			(1.594)	(0.995)			(1.332)	(4.177)			(3.271)	(3.776)
Negative Macro Shock*Public Dummy			4.049	4.179			−3.709	−3.799			−1.489	−0.613
			(1.873)	(1.354)			(1.479)	(2.890)			(2.270)	(4.338)
Positive Macro Shock Square* Public Dummy			0.730	0.765			−0.087	−0.473			3.041	2.768
			(0.300)	(0.161)			(0.187)	(0.772)			(0.960)	(0.689)
Negative Macro Shock Square* Public Dummy			0.540	0.609			−0.317	−0.153			−0.055	0.074
			(0.212)	(0.149)			(0.095)	(0.594)			(0.228)	(0.467)

(continued)

Table 9. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sample Dependent Variable	**Low-Income Countries Loan Growth**				**Middle-Income Countries Loan Growth**				**High-Income Countries Loan Growth**			
Macro Shock	**GDP Growth**	**Output Gap**			**GDP Growth**	**Output Gap**			**GDP Growth**	**Output Gap**		
R^2	0.421	0.548	0.443	0.550	0.159	0.237	0.194	0.238	0.157	0.366	0.156	0.368
No. Countries	15	15	15	15	20	20	25	20	30	29	30	29
No. Private Bank Obs.	2052	1892	2052	1892	4056	3659	5487	3659	8022	4880	8022	4880
No. Public Bank Obs.	743	674	743	674	595	546	778	546	972	725	972	725
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Drop Nationalization in Crisis	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

lending when the economy expands[35] (column 11). It is also worth noting that as the magnitude of the positive shock increases, public banks become more similar to private banks in their lending pattern (columns 11 and 12).

As for the public banks in the low-income group, they have the opposite characteristic in terms of lending variations over the cycle.[36] Overall, it is not significantly different from privately owned banks, whatever the proxy or restrictions used (columns 1 and 2). Then regressions 3 and 4, with or without country-year interaction fixed effects, reveal that public banks are less likely to benefit from the boom phase, but this effect marginally decreases when the size of the positive shock increases (as in the case of the high-income group). And they are more affected during the periods of below-trend growth: in fact, this effect increases as the size of the negative shock increases. As the public banks in less developed countries are rather less procyclical in periods of boom, but more procyclical in periods of bust, it is logical to observe that when the two effects are pooled, as in columns 1 and 2, the average lending cyclicality of public banks is not significantly different from their private counterparts. So failing to distinguish the different stages of the business cycle would wrongly support the view that there is little difference in behavior between public and private banks, while public banks, even after excluding the countries that nationalized ailing banks during a crisis, tend to reduce their lending relatively more during economic downturns.

In short, I find a non-linear relation between economic development and public banks' ability to absorb shocks, whereas one might have expected low-income countries to be keener on using public banking as a political tool to smooth out economic fluctuations. However, the cycle that matters most for low-income countries, with potentially weaker institutions, may not be the economic cycle but rather the political cycle (Dinc 2005; Khwaja and Mian 2005).

---

[35] On the sub-sample of OECD member countries, the deviation from potential output of the economy (instead of output trend) can be used and similar results are obtained, i.e., overall lower cyclicality, especially during phases of expansion. However, in the European case, public banks still reduce their lending significantly less when facing negative shocks.

[36] Likewise, foreign banks in the low-income group are more procyclical, while the effect becomes not statistically significant for the high-income group.

5. The Lending Cyclicality of Public Banks and Their Funding Sources

If public banks lend in a less procyclical manner, especially in times of economic stress, this pattern should be reflected in either their liability structure or the provisions left on the asset side to absorb potential shocks. In other words, the less cyclical lending policy of public banks may be associated with a less volatile funding structure (for instance, linked with explicit government support or a different business model) or with more procyclical loan loss provisioning.

5.1 Middle- and High-Income Countries Have Less Volatile Funding Sources in Bad Times

The evolution of the liability side of public banks in middle- and high-income countries is displayed in table 10.

If public banks in middle-income countries benefit from the upside by increasing both their wholesale (columns 1–3) and their long-term funding (columns 4–6), wholesale funding is less subject to a sudden dry-up in the case of a bad macro shock, which can sustain less cyclical lending practices (column 3).

In high-income countries, public banks appear to rely less on short-term funding captured by the growth rate of money-market funding[37] during expansionary phases (columns 7–9), so that their reliance on wholesale funding is less cyclical, which is consistent with the lower procyclicality of public bank lending, especially during booms. Public bank lending growth in developed countries is also restricted by a more limited expansion of their longer-term funding maturities (column 12).

These two complementary effects are in line with the "dark side" view of wholesale funding, which posits that wholesale markets create severe liquidity risks in the case of negative news (Huang and Ratnovski 2010). As a matter of fact, during a downturn, public ownership may act as a guarantee against possible losses and, for

[37]The same results are obtained by looking at the share of short-term funding broadly defined as total liabilities net of deposits, other liabilities, long-term funding, and total reserves.

Table 10. Bank Funding as a Potential Source of Balance Sheet Cyclicality: Middle- and High-Income Countries

The sub-sample of countries by level of development roughly follows the classification of the World Bank. The left-side variable is the growth rate of a balance sheet variable. The proxy of the macroeconomic shock is GDP growth or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. When looking at the homogeneous reaction of the growth rate of a balance sheet variable across the business cycle, the equation estimated with the within estimator is similar to equation (1). The additional effect of being publicly owned on the co-movement between the balance sheet variable and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. With two buckets, positive or negative macro shocks, the equation estimated using the within estimator is similar to equation (2). The additional effect of being publicly owned during a crisis is captured by the interaction between the proxy for the macro shock, the dummy for the negative macro shock, and the public ownership dummy. The usual set of covariates is used but not reported. The use of country-year interaction fixed effects requires a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sample	**Middle-Income Countries**						**High-Income Countries**					
Dependent Variable	**Growth of Money-Market Funding**			**Growth of Long-Term Funding**			**Growth of Money-Market Funding**			**Growth of Long-Term Funding**		
Macro Shock	**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**	
Output Gap		6.822	−4.777		−4.60	−4.789		1.344	−13.04		12.525	−0.509
		(1.916)	(3.049)		(1.502)	(0.701)		(1.275)	(1.361)		(0.610)	(1.753)
GDP Growth	−1.274	−3.484	−4.923	0.114	3.334	−0.982	5.051	1.329	4.076	3.095	−1.845	2.710
	(0.342)	(0.925)	(1.297)	(0.771)	(0.310)	(0.552)	(1.175)	(0.919)	(0.439)	(0.567)	(0.306)	(0.175)
Positive Shock* Public Dummy			10.94			6.307			−7.204			−7.368
			(2.265)			(1.674)			(3.275)			(3.578)
Negative Shock* Public Dummy			−6.939			−0.452			−4.851			5.026
			(2.921)			(1.970)			(2.914)			(2.423)
Macro Shock* Public Dummy	−0.447	2.323		0.179	3.137		−3.665	−5.657		−2.299	−0.951	
	(1.041)	(1.279)		(0.508)	(0.894)		(1.465)	(1.930)		(0.520)	(2.170)	

(continued)

Table 10. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sample	**Middle-Income Countries**						**High-Income Countries**					
Dependent Variable	**Growth of Money-Market Funding**			**Growth of Long-Term Funding**			**Growth of Money-Market Funding**			**Growth of Long-Term Funding**		
Macro Shock	**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**	
R^2	0.294	0.291	0.300	0.209	0.219	0.220	0.295	0.289	0.289	0.238	0.239	0.242
No. Countries	19	19	19	19	19	19	25	25	25	29	29	29
No. Private Bank Obs.	1535	1535	1535	1789	1789	1789	2143	2143	2143	3039	3039	3039
No. Public Bank Obs.	248	248	248	273	273	273	415	415	415	512	512	512
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Drop Nationalization in Crisis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

instance, discourage wholesale withdrawals when economic conditions deteriorate. Moreover, public banks tend to engage more in relationship lending (Delgado, Salas, and Saurina 2007) and thus try to acquire more private information; but this activity requires more monitoring on behalf of investors and the bank has to pay a premium on outside finance. Thus public banks may have an incentive to rely less on short-term funding, as observed for middle- and high-income countries, and favor longer-term funding sources.[38]

5.2 Low-Income Countries Have More Volatile Funding Sources in Bad Times

The evolution of the liability side of public banks in low-income countries is displayed in table 11.

The funding structure of public banks in low-income countries seems to rely less on short-term money-market funds during expansionary phases, but results suggest that both short- and long-term funding may be more cyclical overall (respectively, columns 1 and 5 for significant results, but insignificant in columns 2 and 4). Thus it is more appropriate to look at the cyclical behavior of the ratio of possibly volatile over more stable funding.

As proposed by Hahm, Shin, and Shin (2012), the vulnerability of a bank on the liabilities side can be measured by the evolution of the non-core liabilities ratio, i.e., the ratio of less stable funding sources (non-core liabilities) over customer deposits (core liabilities). This reflects the growing financing needs that cannot be met with traditional deposits. The results in columns 7 and 9 show that the non-core liabilities ratio is more procyclical for public banks and decreases more in the case of a bad macro shock, whereas it is less cyclical and mostly non-significant for other income groups. Thus, the larger procyclicality of public bank lending during downturns

[38] Customer deposits, another type of short-term finance (as they can be withdrawn without any restrictions), do not move along the cycle significantly differently for public versus private banks. Indeed, customer deposits are usually considered to be sluggish (see, e.g., Song and Thakor 2007) due to deposit insurance schemes available to all banks, except maybe during periods of extreme stress with possible "flight to quality" towards banks directly backed by the government (e.g., in Russia, see Karas, Schoors, and Weill 2008, p. 26).

Table 11. Bank Funding as a Potential Source of Balance Sheet Cyclicality: Low-Income Countries

The sub-sample of countries by level of development roughly follows the classification of the World Bank. The left-side variable is the growth rate of a balance sheet variable. The ratio of non-core liabilities is defined as liabilities other than customer deposits over the traditional (or core) funding source, i.e., customer deposits. The proxy of the macroeconomic shock is GDP growth or the HP-filtered output gap. Public ownership is defined as ultimate ownership (*GOB_UO50*), i.e., the indirect public ownership of more than 50% of a bank. When looking at the homogeneous reaction of the growth rate of a balance sheet variable across the business cycle, the equation estimated with the within estimator is similar to equation (1). The additional effect of being publicly owned on the co-movement between the balance sheet variable and macroeconomic shocks is captured by the interaction between the proxy for the macro shock and the public ownership dummy. With two buckets, positive or negative macro shocks, the equation estimated with the within estimator is similar to equation (2). The additional effect of being publicly owned during a crisis is captured by the interaction between the proxy for the macro shock, the dummy for the negative macro shock, and the public ownership dummy. The usual set of covariates is used but not reported. The use of country-year interaction fixed effects requires a more balanced sample starting in 1999; in this case, time-varying variables at the country level are not estimated. Country clustered robust standard errors are in parentheses.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent Variable	**Growth of Money-Market Funding**			**Growth of Long-Term Funding**			**Growth of Ratio of Non-Core Liabilities**			**Growth of Loan Loss Provisions over Net Income**		
Macro Shock	**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**	
Output Gap		−6.890	−26.905		−5.109	−2.674		−0.107	3.713		−3.437	2.073
		(4.731)	(4.586)		(1.267)	(1.322)		(0.751)	(0.439)		(3.560)	(3.720)
GDP Growth	−1.889	−2.340	14.307	4.830	3.296	3.176	−0.267	−2.733	−2.870	3.754	0.801	−0.409
	(3.326)	(0.291)	(0.379)	(0.822)	(0.412)	(1.039)	(0.181)	(0.203)	(0.395)	(2.341)	(0.881)	(1.196)
Positive Shock* Public Dummy			−9.624			3.911			−2.804			10.647
			(2.316)			(3.151)			(5.486)			(9.066)
Negative Shock* Public Dummy			0.245			1.976			7.641			3.210
			(2.171)			(3.205)			(1.946)			(2.642)
Macro Shock* Public Dummy	2.731	−3.306		−0.406	2.769		1.165	2.824		5.375	8.101	
	(1.143)	(1.942)		(0.763)	(1.067)		(0.447)	(1.618)		(2.527)	(2.128)	

(continued)

Table 11. (Continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Dependent Variable	**Growth of Money-Market Funding**			**Growth of Long-Term Funding**			**Growth of Ratio of Non-Core Liabilities**			**Growth of Loan Loss Provisions over Net Income**		
Macro Shock	**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**		**GDP Growth**	**Output Gap**	
R^2	0.163	0.161	0.162	0.141	0.143	0.143	0.133	0.130	0.133	0.195	0.193	0.194
No. Countries	13	13	13	15	15	15	15	15	15	15	15	15
No. Private Bank Obs.	773	773	773	947	947	947	1705	1705	1705	1040	1040	1040
No. Public Bank Obs.	391	391	391	471	471	471	603	603	603	396	396	396
Bank and Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Drop Nationalization in Crisis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Drop Nationalizations 2008–10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*p < 0.10, **p < 0.05, ***p < 0.01.

observed for low-income countries maps into a less stable funding structure in the case of a negative shock.

If public banks in low-income countries are constrained on their liability side during downturns, they make loan loss provisions more procyclically, which should prevent excessive loan expansion and limit loan deterioration and, as a consequence, favor more countercyclical lending (columns 10 and 11). But this could also arise as a result of lower provisioning in periods of negative shock—for instance, if public banks prefer to roll over their loan book rather than write off non-performing loans, an issue which is beyond the scope of this paper.

6. Conclusion

This paper examines the extent to which public banks display a different pattern in their lending behavior not only according to macroeconomic fluctuations but also across the stages of economic development.

Public bank lending, even when restricted to commercial banks, is less reactive to economic fluctuations. This is especially true in periods of economic downturn: public banks are able to cut back on their new loans less when hit by a negative macroeconomic shock. But as the size of the negative shock increases, the ability of public banks to absorb the shock and lean against the wind is more limited. This asymmetry over the business cycle is particularly relevant for countries in the middle-income group, while public banks in low-income countries have a lending policy that does not ease so much in the case of positive shocks but tightens more in the case of negative ones. This lending pattern is reflected on the liability side by a different funding structure, so that the vulnerability of wholesale funds and non-deposit financing is a consistent explanation for the heterogeneity of public bank lending cyclicality. Moreover, nationalizations during a banking crisis have a tendency to blur the picture due to their correlation with public banking: one has to distinguish public banks which can engage in alternative lending practices from recently nationalized banks which need restructuring and downsizing. Conversely, privatized banks are associated with a shift from low to high lending cyclicality, which is to be expected if ownership does indeed influence lending policies.

The underlying question behind the cyclicality of lending by public banks is their ability to efficiently manage their loan portfolio and funding structure in such a way that their explicit public support allows them to lean against the wind without experiencing any larger default risks (despite larger operational risks; Iannotta, Nocera, and Sironi 2013). This apparently desirable short-term property of public banks calls for more empirical study to investigate the issues of allocation efficiency and corporate governance. For instance, if public banks are less efficient in their monitoring, they can lend in a less procyclical way, but without necessarily ensuring a good allocation of resources (Duprey 2013). Likewise, a different business model may favor more stable lending but may also be associated with more credit forbearance or delayed loan deterioration, which may make public bank lending look less cyclical. Thus the short-term and long-term views of public banking could be two sides of the same coin, an inviting avenue for future research.

References

Allen, B., G. Clarke, R. Cull, L. Klapper, and G. Udell. 2005. "Corporate Governance and Bank Performance: A Joint Analysis of the Static, Selection, and Dynamic Effects of Domestic, Foreign, and State Ownership." Working Paper No. 3632, World Bank.

Barth, J., G. Caprio, and R. Levine. 2000. "Banking Systems around the Globe: Do Regulation and Ownership Affect Performance and Stability?" Working Paper No. 2325, World Bank.

———. 2004. "Bank Regulation and Supervision: What Works Best?" *Journal of Financial Intermediation* 13 (2): 205–48.

Berger, A., N. Miller, M. Petersen, R. Rajan, and J. Stein. 2005. "Does Function Follow Organizational Form? Evidence from the Lending Practices of Large and Small Banks." *Journal of Financial Economics* 76 (2): 237–69.

Bertay, A. C., A. Demirgüç-Kunt, and H. Huizinga. 2015. "Bank Ownership and Credit over the Business Cycle: Is Lending by State Banks Less Procyclical?" *Journal of Banking and Finance* 50: 326–39.

Cull, R., and M. S. Martinez Peria. 2013. "Bank Ownership and Lending Patterns during the 2008–2009 Financial Crisis: Evidence from Latin America and Eastern Europe." *Journal of Banking and Finance* 37 (12): 4861–78.

Delgado, J., V. Salas, and J. Saurina. 2007. "Joint Size and Ownership Specialization in Bank Lending." *Journal of Banking and Finance* 31 (12): 3563–83.

Dinc, S. 2005. "Politicians and Banks: Political Influences on Government-Owned Banks in Emerging Markets." *Journal of Financial Economics* 77 (2): 453–79.

Duprey, T. 2013. "Heterogeneous Banking Efficiency: Allocative Distortions and Lending Fluctuations." Working Paper No. 464, Banque de France.

Duprey, T., and M. Lé. 2014. "Bankscope Dataset: Getting Started." Technical Document.

Foos, D. 2009. "Lending Conditions, Macroeconomic Fluctuations, and the Impact of Bank Ownership." Working Paper.

Galindo, A., and A. Micco. 2004. "Do State-Owned Banks Promote Growth? Cross-Country Evidence for Manufacturing Industries." *Economics Letters* 84 (3): 371–76.

Gerschenkron, A. 1962. *Economic Backwardness in Historical Perspective.* Cambridge, MA: Harvard University Press.

Hahm, J.-H., H. Shin, and K. Shin. 2012. "Non-Core Bank Liabilities and Financial Vulnerability." NBER Working Paper No. 18428.

Huang, R., and L. Ratnovski. 2010. "The Dark Side of Bank Wholesale Funding." IMF Working Paper No. 10/170.

Iannotta, G., G. Nocera, and A. Sironi. 2007. "Ownership Structure, Risk and Performance in the European Banking Industry." *Journal of Banking and Finance* 31 (7): 2127–49.

———. 2013. "The Impact of Government Ownership on Bank Risk." *Journal of Financial Intermediation* 22 (2): 152–76.

Karas, A., K. Schoors, and L. Weill. 2008. "Are Private Banks More Efficient than Public Banks? Evidence from Russia." BOFIT Discussion Paper No. 3.

Khwaja, A., and A. Mian. 2005. "Do Lenders Favor Politically Connected Firms? Rent Provision in an Emerging Financial Market." *Quarterly Journal of Economics* 120 (4): 1371–1411.

La Porta, R., F. Lopez-de-Silanes, and A. Shleifer. 2002. "Government Ownership of Banks." *Journal of Finance* 57 (1): 265–301.

Leonya, L., and R. Romeub. 2011. "A Model of Bank Lending in the Global Financial Crisis and the Case of Korea." *Journal of Asian Economics* 22 (4): 322–34.

Megginson, W. 2005. "The Economics of Bank Privatization." *Journal of Banking and Finance* 29 (8–9): 1931–80.

Mian, A. 2006. "Foreign, Private Domestic, and Government Banks: New Evidences from Emerging Markets." Mimeo, University of Chicago.

Micco, A., and U. Panizza. 2006. "Bank Ownership and Lending Behavior." *Economics Letters* 93 (2): 248–54.

Micco, A., U. Panizza, and M. Yanez. 2007. "Bank Ownership and Performance: Does Politics Matter?" *Journal of Banking and Finance* 31 (1): 219–41.

Ravn, M., and H. Uhlig. 2002. "On Adjusting the Hodrick-Prescott Filter for the Frequency of Observations." *Review of Economics and Statistics* 84 (2): 371–76.

Roodman, D. 2009. "How to Do xtabond2: An Introduction to Difference and System GMM in Stata." *The Stata Journal* 9 (1): 86–136.

Sapienza, P. 2004. "The Effects of Government Ownership on Bank Lending." *Journal of Financial Economics* 72 (2): 357–84.

Shleifer, A., and R. W. Vishny. 1994. "Politicians and Firms." *Quarterly Journal of Economics* 109 (4): 995–1025.

Song, F., and A. V. Thakor. 2007. "Relationship Banking, Fragility, and the Asset-Liability Matching Problem." *Review of Financial Studies* 20 (6): 2129–77.

Real-Time Model Uncertainty in the United States: "Robust" Policies Put to the Test*

Robert J. Tetlow
Division of Monetary Affairs
Federal Reserve Board

I study forty-six vintages of FRB/US, the principal macro model used by the Federal Reserve, as measures of real-time model uncertainty and examine the robustness of commonly applied, simple monetary policy rules. Model uncertainty turns out to be a substantial problem: key model properties differ in important ways across model vintages, as do the optimized parameterizations of candidate rules. Among the simple monetary policy rules considered are rules that eschew feedback on the output gap, rules that target nominal income growth, and rules that allow for time variation in the equilibrium real interest rate. Many rules that previous research has shown to be robust in artificial economies would have failed to provide adequate stabilization in the real-time, real-world environment seen by the Federal Reserve staff. I identify certain policy rules that would have performed relatively well, and characterize their key features to draw more general lessons about the design of monetary policy under model uncertainty.

JEL Codes: E37, E5, C5, C6.

*The working paper version of this paper and others can be found at http://www.roberttetlow.com. I thank Flint Brayton and Dave Reifschneider for helping me interpret historical model changes and for valuable discussions. I thank Bill Branch, Ben Friedman, and an anonymous referee for helpful comments, and Sean Taylor and Trevor Davis for dedicated research assistance. All remaining errors are mine. The views expressed in this paper are those of the author alone and do not necessarily represent those of the Federal Reserve Board or other members of its staff. Author contact: Robert Tetlow, Federal Reserve Board, Washington, D.C. 20551. E-mail: rtetlow@frb.gov.

1. Introduction

> "We have involved ourselves in a colossal muddle, having blundered in the control of a delicate machine, the working of which we do not understand."
>
> — John Maynard Keynes, *The Great Slump of 1930* (December 1930)

Over the twenty years since the Taylor (1993) rule was introduced, there has been an explosion of work studying the characteristics of monetary policy rules in general and simple, interest rate feedback rules in particular. While considerable insight has come out of this literature, so has a fundamental critique, namely that results formulated in this way may not be robust to misspecification of the underlying model. Keynes's metaphor of the economy as a "delicate machine . . . which we do not understand" seems as apt today as it was in 1930.

It follows from that lack of understanding that a principal concern for policymakers is uncertainty, and how to deal with it. The fast-growing literature on model uncertainty seeks answers to this question; see, inter alia, Levin, Wieland, and Williams (1999), Tetlow and von zur Muehlen (2001), Onatski and Williams (2003), Levin et al. (2006), Brock, Durlauf, and West (2007), and Taylor and Wieland (2012).[1] This strand often employs the *rival models* method of analysis wherein the researcher posits two or more alternative models of the economy and employs statistical or decision-theoretic techniques to find a policy rule that performs "well" in each of the posited models; see, e.g., McCallum (1988). While this approach has produced interesting and useful results, it is hampered by the artificiality of the environment in which it has typically been employed. In nearly all cases, the models under consideration are highly abstract and do not fit the data well, useful perhaps for making narrow

[1] Two other aspects of uncertainty, relevant to monetary policymaking, are *parameter uncertainty* (see, e.g., Brainard 1967, Söderström 2002, Walsh 2004, and Kimura and Kurozumi 2007) and *data uncertainty* (Aoki 2003, Jääskelä and Yates 2005). These subject areas should be regarded as complementary to the study of model uncertainty.

points, but not to be taken seriously as tools for monetary policy design.[2]

Virtually absent from the above characterization of the literature is the real-time analysis of model uncertainty. At one level, this is not surprising; after all, while it is easy to conceptualize changing views about what the true model might be, it is more difficult to imagine the laboratory in which such an analysis could be conducted. That is, however, exactly what this paper provides. My laboratory is the Federal Reserve Board staff and the FRB/US model. I examine time variation in model properties, and hence model uncertainty, as it was seen *in real time* by the Federal Reserve Board staff. I do this using forty-six vintages of the Board staff's FRB/US model, or four per year, that were actually used for forecasting and policy analysis during the period from July 1996 to October 2007, examining how the model specification, coefficients, databases, and stochastic shock sets changed from vintage to vintage as new and revised data came in. The advantage provided is that I can focus on those aspects of model uncertainty that are germane to policy decisions, using a model that is used to formulate advice for those decisions.

The relevance of the model is unquestionable: since its introduction in July 1996, the FRB/US model has been used continuously for communicating ideas to the Board of Governors and the Federal Open Market Committee (FOMC). All of the staff's alternative scenarios focusing on domestic economic issues during this period were conducted using the model; forecast confidence intervals are computed using FRB/US, as are optimal policy exercises that are presented to the FOMC. In his 1998 monograph on his time as Vice Chairman of the Federal Reserve Board, Alan Blinder notes (p. 12) the important role that FRB/US simulations played in guiding his thinking; and Blinder and Yellen (2001) made extensive use of simulations of the FRB/US models to explain the boom in the U.S. economy in the 1990s.

[2]An illuminating exception to this rule is the paper of Levin et al. (2006), which uses an estimated DSGE model. Comments on this paper by Walsh (2006) express doubts that the current generation of DSGE models is sufficiently advanced to be taken seriously for this purpose.

Armed with these forty-six vintages of the model, I ask whether the policy rules that have been promoted as robust in one environment or another are in fact robust in this real-world context.

The first policy rule I study, and the one that serves as my benchmark for comparison, is the familiar Taylor (1993) rule, although I use parameterizations that are optimal for the model vintages that are interesting. I also consider three rules that take up the argument of Orphanides (2001), among others, that the inherent difficulty in conditioning policy on unobservable constructed variables like output gaps means that policy should eschew feedback on latent variables altogether. Two candidate rules follow Bennett McCallum (1988) by keying off of nominal output growth. A nominal output growth rule establishes a nominal anchor but unlike, say, an inflation-targeting rule, makes no explicit call on whether shocks are real or nominal; because of this, it is arguably less susceptible to misspecification of the supply side and of the incidence of supply shocks. Two rules build off of the finding of Levin et al. (2006) to the effect that policy should respond to nominal wage inflation instead of price inflation. In this way, the policymaker pays particular attention to the labor market, arguably the part of the economy that, from a neoclassical perspective, is the most distorted.

This paper goes a number of steps beyond previous contributions to the literature. As already noted, it goes beyond the extant rival models literature through its novel and efficacious focus on models that are actually used in a policy environment. It also goes beyond the literature on parameter uncertainty. That literature assumes that parameters are random but the model is fixed over time: misspecification is simply a matter of sampling error. Model uncertainty is a thornier problem, in large part because it often does not readily lend itself to statistical methods of analysis. I explicitly allow the models to change over time in response not just to the data but to the economic issues of the day.[3] Finally, as already noted, this paper

[3]There have been a number of valuable contributions to the real-time analysis of monetary policy issues. Most are associated with data and forecasting. See, in particular, the work of Croushore and Stark (2001) and a whole conference on the subject, details of which can be found at http://www.phil.frb.org/econ/conf/rtdconfpapers.html. An additional, deeper layer of real-time analysis considers revisions to unobservable state variables, such as potential output; Athanasios Orphanides, alone or with co-authors, has

does all this within a class of possible models that is undeniably realistic.

The analysis presented herein is, of course, based on the U.S. economy and the FRB/US model. However, uncertainty, in its various forms, is of concern for monetary authorities the world over as it is for other decision makers. Real-time data issues and data uncertainty more generally have garnered a great deal of attention in the United Kingdom; see, e.g., Garratt and Vahey (2006) and Garratt et al. (2007) and references therein. In the euro area, Giannone, Reichlin, and Sala (2005) study real-time uncertainty for its implications for monetary policy.[4]

The rest of this paper proceeds as follows. The second section begins with a very brief discussion of the FRB/US model in generic terms, and the model's historical archives. The third section compares model properties by vintage. To do this, I document changes in real-time "model multipliers" and compare them with their ex post counterparts. The fourth section computes optimized Taylor-type rules and compares these to commonly accepted alternative policies in a stochastic environment. The fifth section examines the stochastic performance of candidate rules for two selected vintages, the December 1998 and October 2007 models. A sixth and final section sums up and concludes.

2. Forty-Six Vintages of the FRB/US Model

The FRB/US model came into production in July 1996 as a replacement for the venerable MIT-Penn-SSRC (MPS) model. The main objectives guiding the development of the model were that it be useful for both forecasting and policy analysis; that expectations

---

been at the vanguard of this issue; see, e.g., Orphanides et al. (2000). See also Giannone, Reichlin, and Sala (2005) for a sophisticated, real-time analysis of the history of FOMC behavior.

[4]With regard to fiscal policy, Cimadomo (2008) and Giuliodori and Beetsma (2008) uncover important implications of real-time data uncertainty and, indirectly, model uncertainty for the measurement of fiscal stance and the conduct of fiscal policy for the OECD countries and the euro area, respectively. Whole conferences have been organized just on the need for real-time data for the euro area; e.g., the Center for Economic Policy Research conference "Needed: A Real Time Database for the Euro-Area," June 13–14, 2005, in Brussels (http://www.cepr.org/meets/wkcn/1/1632/papers/).

be explicit; that important equations represent the decision rules of optimizing agents; that the model be estimated and have satisfactory statistical properties; and that the full-model simulation properties match the "established rules of thumb regarding economic relationships under appropriate circumstances," as Brayton and Tinsley (1996, p. 2) put it. To address these challenges, the staff included within the model's structure an expectations block, and with it, a fundamental distinction between intrinsic model dynamics and expectational dynamics. Two versions of expectations formation were envisioned: VAR-based expectations and perfect foresight, although mixtures of those two classes of expectations formation can and have been implemented.

The key features influencing the monetary policy transmission mechanism in the FRB/US model are the effects of changes in the federal funds rate on asset prices and from there to expenditures. From this, long-term real interest rates are determined, which in turn affect stock prices (and hence private wealth) and exchange rates. The model's wage-price block has always shared the same basic features: sticky wages and prices, expected future excess demand in the goods and labor markets that influences price and wage setting, and a channel through which productivity affects real and nominal wages. That said, as we shall see, there have been substantial changes over time in both (what we may call) the interest elasticity of aggregate demand and the effect of excess demand on inflation.

In this paper, I will be working exclusively with the VAR-based expectations version of the model. Typically it is the multipliers of this version of the model that are reported to Board members when they ask "what-if" questions. This is the version that is used for forecasting and most of the policy analysis by the Federal Reserve staff, including, as Svensson and Tetlow (2005) demonstrate, policy-optimization experiments. Thus, the pertinence of using this version of the model for the question at hand is unquestionable. What could be questioned, on standard Lucas critique grounds, is the validity of the simple-rule optimizations, given that expectations are not fully rational. However, the period under study is one entirely under the leadership of a single Chairman, and I am aware of no evidence to suggest that there was a change in regime during this period. So, as Sims and Zha (2006) have argued, it seems likely that the perturbations to policies encompassed by the range of policies studied below are not large enough to induce a change in expectations formation.[5] Moreover, in an environment such as the one under study, where changes in the non-monetary part of the economy are likely to dwarf the monetary policy perturbations, it seems safe to assume that private agents were no more rational with regard to their anticipations of policy than the Federal Reserve staff was about private-sector decision making.[6] In their study of the evolution of the Federal Reserve beliefs over a longer period of time, Romer and Romer (2002) ascribe no role to the idea of rational expectations. Moreover, Rudebusch (2002) shows that issues of model uncertainty are often of second-order importance in linear rational expectations models. Thus the VAR-based expectations case is arguably the more quantitatively interesting one.

There is not the space here for a complete description of the model. The working paper version of this article contains a more generous description of model features and a more detailed characterization of economic history over the period under study with reference to how that history affected the construction of various model vintages; see also Brayton and Tinsley (1996), Brayton et al. (1997), Reifschneider, Tetlow, and Williams (1999), and Tetlow and Ironside (2007).

Since its inception in July 1996, the FRB/US model code, the equation coefficients, the baseline forecast database, and the list of stochastic shocks with which the model would be stochastically simulated have all been stored in model archives, one for each of the eight forecasts the Board staff conducts every year. Because it is releases of National Income and Product Accounts (NIPA) data that typically induce reassessments of the model, I use four archives per year, or forty-six in total, the ones immediately following NIPA preliminary releases.[7]

[5] The model's VAR-based expectations code does allow for shifting in the public's perceptions of the long-run real federal funds rate and the target rate of inflation, but not in the elasticities conditional on those beliefs. See Brayton and Tinsley (1996) for details.

[6] A complete set of rational expectations vintages of the FRB/US model does not exist and, in any case, working with those models is computationally infeasible.

[7] The archives are listed by the precise date of the FOMC meeting in which the forecasts were discussed. For present purposes, such precision is not necessary, so

In what follows, I experiment with each vintage of the model, comparing their properties in selected experiments. Consistent with the real-time philosophy of this endeavor, the experiments I choose are typical of those used to assess models by policy institutions in general and the Federal Reserve Board in particular. They fall into two broad classes. One set of experiments, *model multipliers*, attempts to isolate the behavior of particular parts of the model. A multiplier is the response of a key endogenous variable to an exogenous shock after a fixed period of time. An example is the response of the level of output after eight quarters to a persistent increase in the federal funds rate. The other set of experiments judge the stochastic performance of the model and are designed to capture the full-model properties under fairly general conditions. So, for example, I will compute by stochastic simulation the optimal coefficients and economic performance of simple rules, conditional on a model vintage, a baseline database, and a set of stochastic shocks.[8]

Model multipliers have been routinely reported to, and used by, members of the FOMC. Indeed, the model's sacrifice ratio—about which I will have more to say below—was used in the very first FOMC meeting following the model's introduction. Similarly, model simulations of alternative policies have been carried out and reported to the FOMC in a number of memos and official FOMC documents.

The archives document model changes and provide a unique record of model uncertainty. As we shall see, the answers to questions a policymaker might ask differ depending on the vintage of the model. The seemingly generic issue of the output cost of bringing down inflation, for example, can be subdivided into several more precise questions, including (i) what would the model say is the output cost of bringing down inflation today? (ii) what would the model

---

I shall describe them by month and year. Thus, the forty-six vintages I use are, in 1996, July and November; then, typically thereafter the months would be January (but often February), May, August (but occasionally July), and November (but twice October and once December). Nothing of importance is lost from the analysis by excluding every second vintage from consideration.

[8]Each vintage has a set of variables that are shocked for stochastic simulations using bootstrap methods. The list of shocks is a subset of the model's complete set of residuals because other residuals are treated not as shocks but as measurement error. The set of shocks varies with the model vintage according to vintage-specific variable data construction and the period over which the shocks are drawn.

of today say the output cost of bringing down inflation would have been in December 1998? and (iii) what would the model have said in December 1998 was the output cost of disinflation at that time? These questions introduce a time dependency to the issue that rarely appears in other contexts.

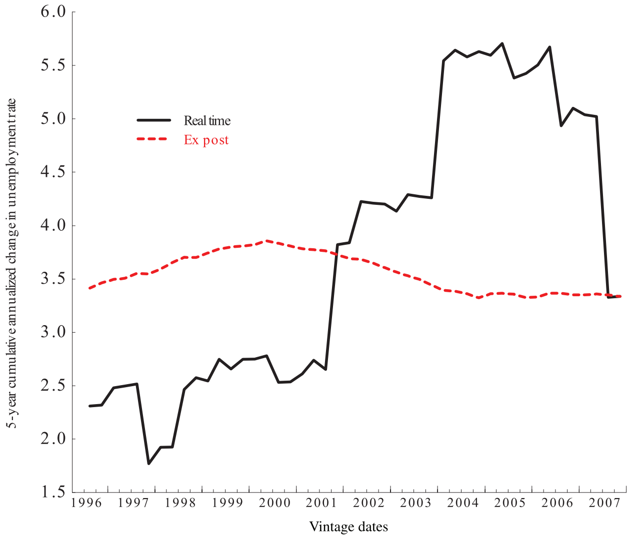
3. Model Multipliers in Real Time and Ex Post

In this section, I consider the variation in real time of selected model multipliers. In the interest of brevity, I devote space to just three multipliers. The first is the sacrifice ratio; that is, the cumulative annualized cost measured in terms of increased unemployment over five years of permanently reducing the inflation rate by 1 percentage point. The second is the funds rate multiplier, defined here as the percentage change in the level of real output after eight quarters that is induced by a persistent 100-basis-point increase in the nominal federal funds rate.[9] In the parlance of an undergraduate textbook closed-economy model, these two multipliers represent the slope of the Phillips curve and the slope of the aggregate demand curve, respectively. To add an international element, I add an exchange rate multiplier—specifically, the percentage change in real GDP associated with a 10 percent appreciation of the trade-weighted exchange value of the U.S. dollar. The sacrifice ratio is the outcome of a five-year simulation experiment; the other multipliers are measured in terms of their effects after eight quarters.

It is easiest to show the results graphically. But before turning to specifics, it is useful to outline how these figures are constructed and how they should be interpreted. In all cases, I show two lines. The solid line is the real-time multiplier by vintage. Each point on the line represents the outcome of the same experiment, conducted on the model vintage of that date, using the baseline database at that point in history. Thus at each point shown by the solid line, the model, its coefficients, and the baseline all differ. The dashed line shows what I call the ex post multiplier. The ex post multiplier is computed using the most recent model vintage for each date; the

[9] These multipliers could have been defined differently; however, the qualitative conclusions would be no different for any reasonable alternative.

Figure 1. Real-Time and Ex Post Sacrifice Ratios, by Model Vintage



only thing that changes for each point on the dashed line is the initial conditions under which the experiment is conducted. Because the multipliers for linear models are independent of initial conditions, examining the dashed line gives an indication of how much of the time variation shown in the solid line arises from the initial conditions and associated model non-linearities.

Now let us look at figure 1, which shows the sacrifice ratio.[10] Let us focus on the dashed line first. It shows that for the October 2007 model, the sacrifice ratio is essentially constant over time. So if the staff were asked to assess the sacrifice ratio, or what the sacrifice ratio would have been in, say, December 1998, the answer based on the October 2007 model would be the same: about 3-1/4, meaning it would take that many percentage-point years of unemployment

[10]The experiment is conducted by simulation, setting the target rate of inflation in a Taylor rule to 1 percentage point below its baseline level. The sacrifice ratio is the cumulative annualized change in the unemployment rate, undiscounted, relative to baseline, divided by the change in personal consumption expenditure (PCE) inflation after five years. Other rules may produce somewhat different sacrifice ratios but the same profile over time.

to bring down inflation by 1 percentage point. Now, however, look at the solid line. Since each point on the line represents a different model, and the last point on the far right of the line is the October 2007 model, the dashed line and the solid line must meet at the right-hand side in this and all other figures in this section. But notice how much the real-time sacrifice ratio has changed over the twelve-year period of study. Had the model builders been asked in December 1998 what the sacrifice ratio was, the answer based on the February 1997 model would have been about 2-1/2. Prior to a revision in mid-2007 that was undertaken expressly, in larger part, to reduce it, the sacrifice ratio for vintages from 2004 to 2006 was of the order of 5-1/2, or more than double what it was in the 1990s.

The sacrifice ratio is a crucial statistic for any central bank model. On the one hand, it describes the cost of bringing down inflation, given that one inherits a higher inflation rate than is desired because of, say, a supply shock. From this perspective, a high sacrifice ratio is a bad thing. On the other hand, a high sacrifice ratio reflects a flat Phillips curve; that is, shocks to aggregate demand of a given magnitude will elicit smaller changes in inflation than otherwise. From this perspective, a high sacrifice ratio is a good thing. Which effect dominates depends on the incidence of supply and demand shocks.

The primacy of the model's sacrifice ratio to policy debates is clear from FOMC transcripts. It was, for example, a topic of discussion at the first FOMC meeting following the introduction of the model.[11] Similarly, the February 1, 2000 meeting of the FOMC produced this exchange between Federal Reserve Bank of Minneapolis President Gary Stern and then FOMC Secretary (subsequently Federal Reserve Board Vice Chairman) Donald Kohn:[12]

> Mr. Stern: Let me ask about the Bluebook [FRB/US model simulation] sacrifice ratio. I don't know what your credibility assumption is, but it seems really high.

[11] See http://www.federalreserve.gov/monetarypolicy/files/FOMC19960703meeting.pdf for a transcript of the July 2–3, 1996 meeting of the FOMC, pp. 42–47.

[12] Transcript, FOMC meeting, February 1, 2000, pp. 41–2. Available at http://www.federalreserve.gov/monetarypolicy/files/FOMC20000202meeting.pdf.

> Mr. Kohn: It is a little higher than we've had in the past, but not much. It is consistent with the model looking out over the longer run. It is a fairly high sacrifice ratio, I think, compared to some other models, but it is not out of the bounds.

Kohn was clearly aware that the model's sacrifice ratio had undergone some change and was rightfully cognizant of how it compares against alternative models. As it happens, the increases already incurred in the sacrifice ratio were only the beginning.

The climb in the model sacrifice ratio is striking, particularly as it was incurred over such a short period of time among model vintages with substantial overlap in their estimation periods. Of particular note is the sizable jump in the sacrifice ratio in late 2001 which arose when the staff began estimating the wage and price equations simultaneously, together with other equations to represent the rest of the economy, including a Taylor rule for policy. One might be forgiven for thinking that this phenomenon is idiosyncratic to the model under study. But other work shows that this result is not a fluke.[13] At the same time, as I have already noted, the model builders *did* incorporate shifts in the NAIRU (and in potential output), but found that leaning exclusively on this one story for macroeconomic dynamics in the late 1990s was insufficient. Thus, the revealed view of the model builders contrasts with the idea advanced by Staiger, Stock, and Watson (2001), among others, that changes in the Phillips curve are best accounted for entirely by shifts in the natural rate of unemployment. Toward the end of the decade, a reduction in the sacrifice ratio became an important objective of the specification and estimation of the model's wage-price block; success on this front was achieved through respecification of how long-term inflation expectations evolve over time.

[13] In particular, the same phenomenon occurs to varying degrees in simple single-equation Phillips curves of various specifications using both real-time and ex post data. One paper along these lines is Atkeson and Ohanian (2001). Primiceri (2005) estimates a time-varying VAR model to uncover substantial shifts in the time-series behavior of inflation. Cogley and Sargent (2005) estimate three Phillips-curve models simultaneously and apply Bayesian decision theory to explain why the Federal Reserve did not choose an inflation-stabilizing policy before the Volcker disinflation; that paper also finds substantial time variation in the output cost of disinflation.

Figure 2. Funds Rate Multipliers, by Model Vintage

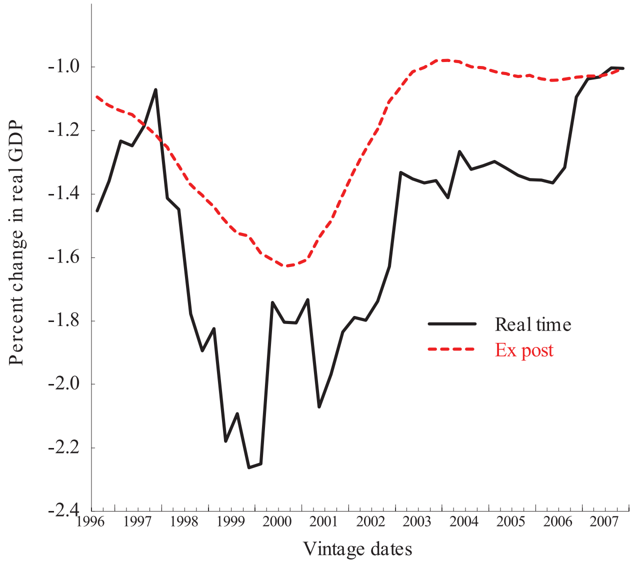


Figure 2 shows the funds rate multiplier; that is, the percentage decrease in the level of real GDP after eight quarters in response to a persistent 100-basis-point increase in the funds rate. In this instance, the dashed line shows important time variation: the ex post funds rate multiplier varies with initial conditions; it is largest, in absolute terms, at about 1.6 percentage point in late 2000, and lowest at the beginning and at the end of the period, at about 1 percent. The non-linearity stems entirely from the specification of the model's stock market equation, which is written in levels, rather than in logs, a feature that makes the interest elasticity of aggregate demand an increasing function of the ratio of stock market wealth to total wealth. The mechanism is that an increase in the funds rate raises long-term bond rates, which in turn bring about a drop in stock market valuation operating through the arbitrage relationship between expected risk-adjusted bond and equity returns. The larger the stock market, the stronger the effect.[14]

[14]The levels relationship of the stock market equation means that the wealth effect of the stock market on consumption can be measured in the familiar "cents

The real-time multiplier, shown by the solid line, is harder to characterize. Two observations stand out. The first is the sheer volatility of the real-time multiplier. In a large-scale model such as the FRB/US model, where the transmission of monetary policy operates through a number of channels, time variation in the interest elasticity of aggregate demand depends on a variety of parameters. Second, the real-time multiplier is almost always smaller than the ex post multiplier. The gap between the two is particularly marked in 2000, when the business cycle reached a peak, as did stock prices. At the time, concerns about possible stock market bubbles were rampant. One aspect of the debate between proponents and detractors of the active approach to stock market bubbles concerns the feasibility of policy prescriptions in a world of model uncertainty.[15] The considerable difference between the real-time and ex post multipliers during this period demonstrates the difficulty in carrying out historical analyses of the role of monetary policy; today's assessment of the strength of those monetary policy actions can differ substantially from what the FRB/US model implied in real time.

The final multiplier covered here is the effect of a sustained 10 percent appreciation of the real exchange value of the U.S. dollar on real output in the United States. The striking change in 1998 in figure 3 corresponds with a shift from a G10 aggregate of trade weights for foreign indexes to a G29 aggregate. The subsequent reversal began with a shift to chain weighting of domestic price indexes in 1999:Q3. In any case, without belaboring the details, the salient fact to take from this figure and others like it that are not shown here is first and foremost the variability of the elasticities.[16]

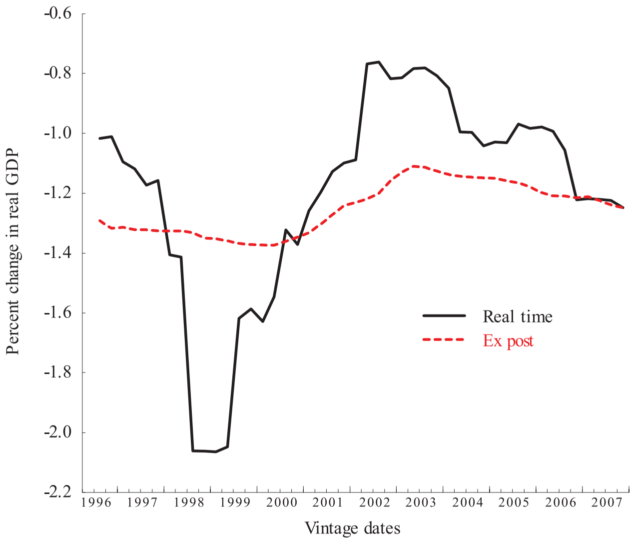
To summarize this section, real-time multipliers show substantial variation over time, and differ considerably from what one would

per dollar" form (of incremental stock market wealth). Also playing a role is the log-linearity (that is, constant elasticity) of the relationship between wealth and consumption.

[15]The "active approach" to the presence of stock market bubbles argues that monetary policy should specifically respond to bubbles. See, e.g., Cecchetti et al. (2000). The passive approach argues that bubbles should affect monetary policy only insofar as they affect the forecast for inflation and possibly output. They should not be a special object of policy. See Bernanke and Gertler (1999).

[16]The working paper version of this article shows and discusses another open-economy multiplier, namely the pass-through non-oil import prices into PCE price inflation. See also Tetlow and Ironside (2007).

Figure 3. Real Exchange Rate Multipliers, by Model Vintage



say ex post the multipliers would be. Moreover, the discrepancies between the two multiplier concepts have often been large at critical junctures over the period under study from 1996 to 2007. It follows that real-time model uncertainty is an important problem for policymakers. The next section quantifies this point by characterizing optimized policies, and their time variation, conditional on these model vintages.

4. Monetary Policy in Real Time

4.1 The Rules

I seek rules that are simple, robust, and effective. In the current context, a monetary policy rule can be described as *robust* if (i) the optimized policy coefficients do not differ in important ways across models *or* (ii) the performance of the economy does not depend in an economically important way on rule parameterization. A robust policy rule can also be described as *effective* if (iii) it performs "well," relative to some benchmark policy rule.

A popular simple monetary policy rule is the canonical Taylor (1993) rule. One reason the Taylor rule is advocated for monetary policy is because of its simplicity in that it calls for feedback on only those variables that are central in a broad class of models; see, e.g., Williams (2003) for an argument along these lines. And indeed many central banks use Taylor rules, or rules much like them, in the assessment of monetary policy and for formulating policy advice, including in the Board staff's presentations of policy options for the FOMC. In the U.S. case, Giannone, Reichlin, and Sala (2005) show that the good fit of simple two-parameter Taylor-type rules can be attributed to the small number of fundamental factors driving the U.S. economy; that is, the two arguments that appear in Taylor rules encompass all that one needs to know to summarize monetary policy in history. In what follows, I will use the Taylor rule, appropriately parameterized, as my benchmark for comparison.

Taylor rules have their detractors. Much of the earlier work on robust policy rules has focused on the importance of estimation and misperception of potential output and the associated mismeasurement of the output gap.[17] Accordingly, some of the rules I consider are those that have been suggested as prophylactics for this problem. In other instances, it is a broader class of latent variables that have been the object of concern. For example, the productivity boom in the United States in the second half of the 1990s brought about misperceptions not just of the *level* of the output gap but also of potential output *growth* going ahead; these concepts in turn have a bearing on the equilibrium real interest rate since in all but the smallest of open economies, the equilibrium real interest rate is determined, in part, by the steady-state growth rate of the economy. The two problems are related but different. Mismeasurement of the *level* of potential output, by itself, induces only a stationary error process. Missing a shift in the *growth rate* of potential represents a more persistent error that affects a wider range of variables, including the equilibrium real interest rate. Accordingly, some of the rules I consider below are intended to address the latter, more complicated, problem.

[17]See, e.g., Orphanides et. al. (2000), Orpanides (2001), and Ehrmann and Smets (2003).

The simple rules employed for this paper are summarized in table 1. In this section, I provide brief descriptions of their features. Most of the analysis is restricted to a class of optimized two-parameter policy rules. This keeps the rules on equal footing in that it is to be expected that adding extra optimized parameters should improve performance, at least for a given model. It also keeps computational costs to a manageable level. Nevertheless, as a check against possible idiosyncrasies in results, I do consider a limited number of three-parameter specifications.

4.1.1 Two-Parameter Policy Rules

The first rule is the familiar Taylor rule which, for short, I will often refer to as "TR." As indicated in the first row of table 1, and in the accompanying notes to the table, the rendition used here differs slightly from Taylor (1993) in that I allow the coefficients to differ depending on the simple-rule optimization discussed below, and I permit the "equilibrium" real rate, rr^*, to vary over time rather than fix it to the constant value of 2 used in the original. Also, in keeping with FOMC practice, the inflation rate used in the rule is the (four-quarter) PCE inflation rate rather the GDP deflator.

In my first bow to the output-gap mismeasurement problem, I also study an inflation-targeting rule (IT); that is, a rule that eschews feedback on the output gap altogether in order to avoid problems from the sort of data and conceptual revisions described in section 2 above, as suggested by Orphanides (2001). For this rule and several others, I allow for instrument smoothing, with the parameter α_r, and allow the term $(1-\alpha_r)(.)$ to pick up the steady-state level of the real interest rate.[18] In addition to IT, I investigate a price-level targeting counterpart of the same specification, PLT, where it should be understood that p_t^* need not be a fixed number; it could instead be (and, for us, is) a predetermined trending path for the

[18]In nearly all works on optimized rules, the steady-state terms are omitted for two reasons: first, the models used are linear, so the steady state can be taken as zero; and second, no allowance is made for shifting steady states. (An exception is Orphanides and Williams 2002, who specifically consider rr^* that shift over time.) Because I am using real models with real databases, and I am considering persistent deviations from steady state—indeed arguably this is a large part of the problem of interest—I need to retain these steady-state terms.

Table 1. Summary of Simple Rules

Name	Rule	Ref.
	Two-Parameter Rules	
Taylor Rule	$r_t = rr_t^* + \widetilde{\pi}_t + \alpha_Y(y_t - y_t^*) + \alpha_\pi(\widetilde{\pi}_t - \pi_t^*)$	TR
Inflation	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_\pi(\widetilde{\pi}_t - \pi_t^*)$	IT
Price Level	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_\pi(p_t - p_t^*)$	PLT
Change in U-Rate	$\Delta r_t = \alpha_\pi(\widetilde{\pi}_t - \pi_t^*) + \alpha_{\Delta u}\Delta u_t$	DUR
Nominal Output 1	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_{\Delta yn}(\Delta\widetilde{yn}_t - \Delta yn_t^*)$	YN1
Nominal Output 2	$r_t = (rr_t^* + \widetilde{\pi}_t) + \alpha_Y(y_t - y_t^*) + \alpha_{\Delta yn}(\Delta\widetilde{yn}_t - \Delta yn_t^*)$	YN2
Wage Growth 1	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_{\Delta w}(\Delta\widetilde{w}_t - \Delta w_t^*)$	WN1
Wage Growth 2	$r_t = rr_t^* + \widetilde{\pi}_t + \alpha_Y(y_t - y_t^*) + \alpha_{\Delta w}(\Delta\widetilde{w}_t - \Delta w_t^*)$	WN2
	Three-Parameter Rules	
Inertial Taylor	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_Y(y_t - y_t^*) + \alpha_\pi(\widetilde{\pi}_t - \pi_t^*)$	TRI
Potential Growth	$r_t = rr_t^* + \widetilde{\pi}_t + \alpha_{\Delta Y*}\Delta y^* + \alpha_Y(y_t - y_t^*) + \alpha_\pi(\widetilde{\pi}_t - \pi_t^*)$	DY*
Inertial YN	$r_t = \alpha_r r_{t-1} + (1-\alpha_r)(rr_t^* + \widetilde{\pi}_t) + \alpha_Y(y_t - y_t^*) + \alpha_{\Delta yn}(\Delta\widetilde{yn}_t - \Delta yn_t^*)$.	YNI

Notes: r is the nominal federal funds rate; rr^* is the "equilibrium" real rate; π is PCE inflation; p is the price level; y is real output; w is the nominal wage rate; u is the unemployment rate; yn is nominal output; a $\sim$ overstrike indicates a four-quarter average; an * superscript indicates a target or equilibrium level of a variable. All variables not expressed as rates are in logs.

(log of the) price level such that successful targeting renders a positive average rate of inflation. The important distinction between a price-level target and an inflation target is that in the event of an inflation surprise, a price-level targeting regime is obliged not just to bring inflation back down to the target level but to bring inflation below target for a time in order to return the price level to its target path.

I will also analyze a Taylor-type rule that substitutes the change in the unemployment rate for the traditional output gap in order to allow a real variable to enter the rule while still minimizing the effects of misperceptions of potential output; see, e.g., Orphanides and Williams (2002). Notice that this rule, designated "DUR," is written in the first difference of the funds rate, a configuration that eliminates the need to condition on the equilibrium real interest rate. As such, the DUR takes a step towards insulation against persistent shocks to productivity and associated mismeasurements of rr^*.

Another much-touted rule is the nominal output growth rule, along the lines suggested by Bennett McCallum (1988) and revisited by Dennis (2001) and Rudebusch (2002). Its purported advantage is that it parsimoniously includes both prices and real output *growth* but without taking a stand on the split between the two; for this reason it is said to be able to withstand productivity shocks. Detractors note that because output typically leads inflation, responding to the sum of the two is not as obviously beneficial as presumed and that fluctuations in productivity growth will imply that the inflation rate is not pinned down, even in the long run. I experiment with two versions. The first is designated with the rubric "YN1," follows the formulation of McCallum and Nelson (1999), and nests the versions studied by Rudebusch (2002). However, because YN1 embodies output growth within its specification, albeit with its coefficient restricted to equal that of GDP price inflation, but not a term for the *level* of resources utilization, I augment the analysis by including a second version, YN2, which has the virtue of being identical to TR except that nominal output growth substitutes for inflation.

I also pick up on the finding of Levin et al. (2006) that a policy that responds to nominal wage inflation (WN1) instead of nominal price inflation performs well across a range of microfounded models.

In this way, the policymaker pays particular attention to that part of the economy that, from a neoclassical perspective, is arguably the most distorted. Like the nominal output growth targeting rule, because wage setting is supposed to reflect both price inflation and labor productivity, the nominal wage growth rule also has the merit of implicitly incorporating changes in trend productivity. Finally, to close the summary of two-parameter rules, in parallel fashion to my nominal output rules, I consider a second version of the nominal wage growth rule, WN2, that replaces the lagged instrument with the output gap.

4.1.2 Three-Parameter Policy Rules

As noted, the benchmark against which all my rules are to be compared is the optimized version of the Taylor rule. It is possible, however, that the two-parameter Taylor rule is too parsimonious to adequately respond to the myriad economic disturbances to which the economy is subjected. In order to address this possibility, I also explore an inertial Taylor rule—let us call it "TRI." This rule is the most commonly studied extension on the static Taylor rule; Williams (2003) argues that the inclusion of the lagged instrument can provide significant benefits in terms of economic outcomes in linearized New Keynesian models; see also English, López-Salido, and Tetlow (2013).

Lastly, acknowledging that persistent shocks to productivity may shift the equilibrium real interest rate, it seems prudent to consider conditioning policy specifically on potential output growth. At the same time, to be realistic, one should use not ex post measures of potential growth but rather the estimates that modelers were working with in real time. This can be done using the rule shown in the penultimate line of the table, called the potential growth rule (DY*), where Δy^* is the *vintage-consistent estimate* of potential output growth. The terms rr^* and $\alpha_{Y*}\Delta y^*$ together can be taken as a reworked estimate of the equilibrium real rate, one that corrects for changes in potential output growth.

Together, these rules encompass a broad range of the rules that have been proposed as robust to model misspecification, and do so in a generic way in that their arguments do not depend on idiosyncrasies of the FRB/US model.

4.2 The Policy Problem

Formally, a policy rule is optimized by choosing the parameters, Φ, within the policy rule, $r = \Phi(x)$, where $\Phi = \{\alpha_i, \alpha_j, \alpha_k\}$ $i, j, k \in \{\pi, y, r_{t-1}, \Delta y^*, \Delta yn, \Delta u, \Delta w\}, i \neq j \neq k$, to minimize a loss function, subject to a given model vintage, $x = f(\cdot)$, and a given set of stochastic shocks, Σ. In the present case, this is written in generic terms as

$$\underset{\langle\Phi\rangle}{MIN} \sum_{i=0}^{T} \beta^i \left[\left(\pi_{t+i} - \pi^*_{t+i}\right)^2 + \lambda_y \left(u_{t+i} - u^*_{t+i}\right)^2 + \lambda_{\Delta r} (\Delta r_{t+i})^2 \right] \tag{1}$$

subject to

$$x_t = f(x_t, \ldots x_{t-m}, z_t, \ldots z_{t-n}, r_t, \ldots r_{t-p}) + v_t \quad m, n, p \geqslant 0 \tag{2}$$

and

$$\Sigma_v = v'v, \tag{3}$$

where u is the unemployment rate, u^* is the vintage-consistent estimate of the natural rate of unemployment, r is the federal funds rate, x is a vector of endogenous variables, and z is a vector of exogenous variables, both in logs, except for those variables measured in rates. Note that $\pi, y, y^*, u, r, rr^*, w, yn \in x$ while $\pi^*, u^* \in z$.[19] In principle, the loss function, (1), could have been derived as the quadratic approximation to the true social welfare function for the FRB/US model. However, it is technically infeasible for a model the size of FRB/US. That said, with the possible exception of the term penalizing the change in the federal funds rate, the arguments to (1) are

[19]The intercept used in the policy rules, where applicable, designated rr^*, is a medium-term proxy for the equilibrium real interest rate. It is an endogenous variable in the model. In particular, $rr^*_t = (1-\gamma)rr^*_{t-1} + \gamma(rn_t - \pi_t)$, where r is the federal funds rate, and $\gamma = 0.05$. As a robustness check, I experimented with adding a constant in the optimized rules in addition to rr^* and found that this term was virtually zero for every model vintage. Note that relative to the classic version of the Taylor rule where rr^* is fixed, this alteration biases results in favor of good performance by this class of rules.

standard.[20] The penalty on the change in the funds rate may be thought of as representing either a hedge against model uncertainty in order to reduce the likelihood of the federal funds rate entering ranges beyond those for which the model was estimated, or as a pure preference of the Committee. Whatever the reason for its presence, the literature confirms that some penalty is needed to explain the historical persistence of monetary policy; see, e.g., Sack and Wieland (2000).

The optimal coefficients of a given rule are a function of the model's stochastic shocks, as equation (3) indicates.[21] The optimized coefficient on the output gap, for example, represents not only the fact that unemployment rate stabilization—and hence, indirectly, output-gap stabilization—is an objective of monetary policy, but also that in economies where demand shocks play a significant role, the output gap will statistically lead changes in inflation in the data; so the output gap will appear because of its role in forecasting future inflation. However, if the shocks for which the rule is optimized turn out not to be representative of those that the economy will ultimately bear, performance will suffer. As we shall see, this dependence will turn out to be significant for the results.

4.3 Computation

Solving a problem like this is easily done for small, linear models; FRB/US, however, is a large, non-linear model. Given the size of the model, and the differences across vintages, I optimized the policy rule coefficients employing a sophisticated derivative-free optimization procedure with distributed processing. Specifically, each vintage of the model is subjected to bootstrapped shocks from its stochastic shock archive. Historical shocks from the estimation period of the key behavioral equations are drawn.[22] In all, 1,500 draws of eighty

[20]Qualitatively speaking, the results are the same if the output gap is substituted for the unemployment gap in (1), provided the proper normalization of the weight is taken to account for the relative size of unemployment gaps and output gaps over the business cycle.

[21]The rules will be optimal in the relevant class, conditional on the stochastic shock set, (3), under anticipated utility as defined by Kreps (1998).

[22]The number of shocks used for stochastic simulations has varied with the vintage, and generally has grown. For the first vintage, forty-three shocks were used, while for the November 2003 vintage, seventy-five were used.

periods each are used for each vintage to evaluate candidate parameterizations. The target rate of inflation is taken to be 2 percent as measured by the annualized rate of change of the personal consumption expenditure price index.[23] The algorithm is described in detail in Gray and Kolda (2004) and Kolda (2004); here I provide just a thumbnail sketch. In the first step, the rule is initialized with a starting guess; that guess and some neighboring points are evaluated. In the case of two-parameter rules, I need only investigate four neighboring points: higher and lower, by some step size, for each of the two parameters, with the initial guess in the middle. The loss function is evaluated for each of the five points, and the one with the lowest loss becomes the center of the next cluster of five points. As the five points become less and less distinguishable from one another, the step size is reduced until the convergence criterion is satisfied.

Optimization of a two-parameter policy rule using a single Intel Xeon 2.8 GHz machine can take over ten hours, depending on the rule; distributed processing speeds things up. Because this exercise is computationally intensive, I am limited in the range of preferences I can investigate. Accordingly, I discuss only one set of preferences: equal weights on output, inflation, and the change in the federal funds rate. This is the same set of preferences that have been used in optimal policy simulations carried out for the FOMC; see Svensson and Tetlow (2005).

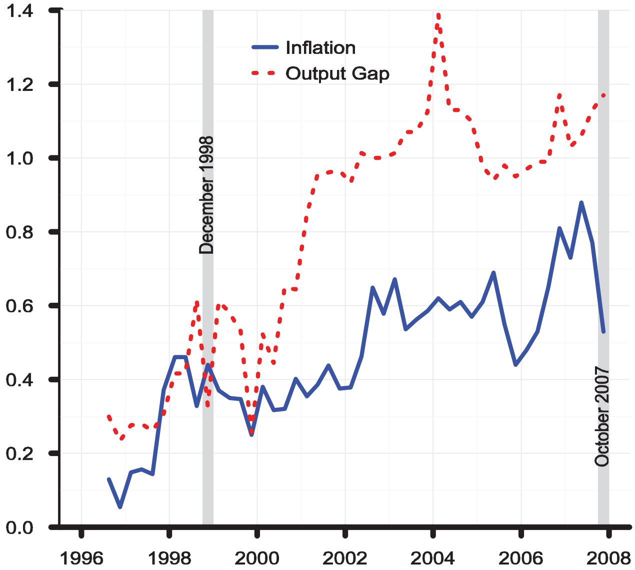
5. Results

5.1 The Taylor Rule

Let us begin with the Taylor rule (TR). In this instance, I provide a full set of results—that is, optimized parameters for each of the forty-six vintages; later I will narrow the focus. The results are best summarized graphically. In figure 4, the solid line is the optimized coefficient for the TR on inflation, α_π, while the dashed line is the feedback coefficient on the output gap, α_Y. Perhaps the most noteworthy observation from figure 4 is the distinct upward creep, on average, in both parameters. The inflation response coefficient never

[23]For these experiments, any reasonable target will suffice since the stochastic simulations effectively randomize over initial conditions.

Figure 4. Optimized Coefficients of the Taylor Rule, by Vintage



actually gets very large: it starts out quite low, and only in the new century does it climb above the 0.5 percent level of the canonical Taylor (1993) rule. The rise over time in the output-gap coefficient is more impressive. It too starts out low, with the first vintage in July 1996 at about 0.1, but then rises more or less steadily thereafter—the late-1999 dip aside—reaching values generally above 1 with the later vintages.[24]

The sharp increase in the gap coefficient in 2001 coincides with the inclusion of a new investment block which, in conjunction with changes to the supply block, tightened the relationship between supply-side disturbances and subsequent effects on aggregate demand, particularly over the longer term.[25] The new

[24]There is also a sharp jump in the gap coefficient over the first two quarters of 2001. One might be tempted to think that this is related to the jump in the sacrifice ratio, shown in figure 1. In fact, the increase in the optimized gap coefficient precedes the jump in the sacrifice ratio.

[25]In essence, the linkage between a disturbance to total factor productivity (TFP) and the desired capital stock in the future was clarified and strengthened

investment block, in turn, was driven by two factors: the earlier inclusion by the Bureau of Economic Analysis of software in the definition of equipment spending and the capital stock, and associated enhanced appreciation on the part of the staff of the importance of the ongoing productivity and investment boom. In any case, while the upward jump in the gap coefficient stands out, it bears recognizing that the rise in the gap coefficient was a continual process.

The point to be taken from figure 4 is that the time variation in model properties, described in section 3, carries over into substantial variation in the optimized TR policy parameters. At the same time, it is clear that time variation in the multipliers is not the sole reason why optimized TR coefficients change. In fact, changes in the stochastic structure of the economy are also in play. To the extent these differences in optimized parameters, conditional on the stochastic shocks, imply significant differences in economic performance, I can say that model uncertainty is a significant problem. I can examine this question by comparing the performance of the optimized TR against other plausible parameterizations. For this exercise and nearly all that follow, I narrow the focus to just two vintages: the December 1998 vintage and the October 2007 vintage. (The optimized Taylor-rule coefficients associated with these vintages are indicated in the figure by the gray bars.) These particular vintages were chosen because they were far apart in time, thereby reflecting as many different views of the world as this environment allows, and because their properties are among the most different of any in the set.

In the next section I examine the implications for economic performance of the TR and the other optimized simple rules for two selected model vintages.

5.2 Optimized Rules and Performance

5.2.1 Two-Parameter Rules

To this point, I have compared model properties and optimized policies but have had nothing directly to say about performance. This

so that an increase in TFP that may produce excess supply in the very short run can be expected to produce an investment-led period of excess demand later on.

section fills this void. I consider the performance, on average, of the model economies under stochastic simulation. I also expand the study to encompass the wider range of simple rules introduced in sections 4.1.1 and 4.1.2. At the same time, in order to make the computational costs feasible, I focus on results for the two selected vintages. Table 2 shows the performance for the complete set of two-parameter rules. The table is divided into two sections, one for each of the December 1998 and October 2007 vintages. In both sections, losses have been normalized on the performance of the optimized Taylor rule so that the efficacy of other rules can be interpreted as multiples of the TR loss.

Before delving into the numbers, it is useful to recall that the results in this table pertain to monetary authorities that understand the nature of the economy they control, including the shocks to which the economy is subject. That is, I am setting aside, for the moment, the issue of model uncertainty, which I take up in the next section. With this in mind, let us focus for the moment on the optimized parameters and normalized losses for the December 1998 vintage shown in table 2. The results show, first, why the TR has been a popular specification for policy design: it renders a very good performance with losses that are lower than nearly all of the alternatives. The one rule that outperforms TR is WN2, shown on line 8, which is identical to the Taylor rule but replaces price inflation with wage inflation. This rule is a version of the rule championed by Levin et al. (2006) on the grounds that in many models, it is wages that are the source of most nominal stickiness. It is not simply feedback on wages that is important to this result, however; the performance of WN1, on line 7, shows that a rule that replaces price inflation with wage inflation as the nominal anchor, but omits direct feedback on the output gap in favor of persistence in funds rate setting through the presence of a lagged funds rate, is the worst rule among those shown. There are other rules that are not far behind the TR in terms of performance, including the (change in) unemployment rate rule, DUR, line 4, with a loss only of 19 percent more than the Taylor rule, and the price-level targeting rule, line 3, which carries a loss only slightly above that of the Taylor rule. This latter result may seem familiar to results seen elsewhere that show strong performance of price-level targets. However, to the best of my knowledge, prior results have been exclusively for linear rational expectations

Table 2. FRB/US Model Performance in Stochastic Simulation*
(two-parameter rule optimizations, selected vintages)

	Parameters →	Anchor	Real	December 1998			October 2007		
Line	**Policy Rule ↓**	i	j	α_i	α_j	*Norm*†	α_i	α_j	*Norm*†
1	Taylor Rule	π	y	0.44	0.33	1.00	0.53	1.17	1.00
2	Inflation Target	π	r	0.87	−0.32	1.44	−0.30	−0.81	4.51
3	Price Level	p	r	8.14	0.46	1.03	14.70	1.14	0.96
4	Change in U-Rate	π	Δu	0.16	−2.52	1.19	0.08	−3.60	0.88
5	Nominal Output 1	Δyn	r	0.20	0.93	1.35	0.37	0.90	1.42
6	Nominal Output 2	Δyn	y	0.02	0.43	1.26	0.02	1.12	1.06
7	Wage Growth 1	Δw	r	1.05	−0.41	1.46	0.63	−0.71	1.57
8	Wage Growth 2	Δw	y	0.72	0.39	0.92	0.09	1.16	1.03

*Loss figures in the October 2007 columns cannot be compared with those in the December 1998 columns. †Average value for equation (1) from 1,500 stochastic simulations over twenty years, normalized so that losses are interpretable as multiples of the loss under the optimized Taylor rule.

models where the powerful role of expectations in strengthening the error-correcting properties of such rules is paramount. That good performance arises from a price-level target under the VAR-based expectations approach is remarkable. Of related interest is the fact that the price-level rule significantly outperforms the IT rule. Inflation targeting allows "bygones to be bygones" in the control of the price level, whereas price-level errors have to be reversed in price-level targeting regimes. Reversing price-level errors is a good thing when agents *know* that the central bank will do this, because anticipated reversals of the price level implies strongly anchored expectations for the inflation rate. When expectations are "boundedly rational," however, the conventional wisdom has been that bringing the price level back to some predetermined path will be all cost and no benefit. We see here that this is not so for the VAR-based expectations of the FRB/US model.

More generally, the performances of the other rules are not greatly different from the Taylor rule; as noted, the WN1 performs the worst, but its loss is only about 1-1/2 times that of the TR, not a good performance but not disastrous either. Evidently, controlling the economy of the December 1998 vintage is a relatively straightforward task.

Let us turn now to the far-right columns, where parallel results are shown for the October 2007 vintage. Here, once again, the TR does pretty well, on average, but in this instance there are two rules that do better, the price-level rule and the DUR. I have already noted that parameterizations of these rules did well in the December 1998 vintage. In addition, two other rules also performed almost as well as the TR: the YN2 and WN2. These rules share two important features. First, they employ feedback on a nominal variable that attempts to correct, albeit indirectly, for trend productivity growth and errors in its measurement. Second, they maintain feedback on the output gap. Thus, notwithstanding the mismeasurement issues associated with persistent changes in productivity *growth*, feedback on the output gap, which is subject to errors in productivity *levels*, is still beneficial, as can be seen by comparing line 6 with line 5, on the one hand, and line 8 with line 7, on the other. In other words, these two rules produce good results but not entirely for the reasons for which these rules were originally advocated.

The last word on this section of the table concerns, once again, the inflation-targeting rule, IT. Its performance controlling the October 2007 vintage could fairly be described as terrible, at 4-1/2 times the loss of the Taylor rule. Qualitatively, this is similar to the results for the December 1998 vintage, but quantitatively much worse. The reasons for this stem from the forementioned tightening of the linkages between the supply block of the model and subsequent aggregate demand fluctuations, together with the nature of the shocks that were incurred during the period over which the two rules are optimized. The rules for the December 1998 vintage are conditioned on shocks from 1981 to 1995, while the October 2007 vintage is conditioned on shocks from 1988 to 2002. The former period was dominated by garden-variety demand shocks, whereas the latter had large and persistent disturbances to aggregate supply—in particular, the productivity boom of the second half of the 1990s. Moreover, many of the key shocks borne during the more recent period were larger than was the case in the earlier period.[26] An implication of productivity booms is that they disrupt the "normal" time-series relationship between output (or employment) and inflation: when output fluctuations are dominated by demand shocks, and prices are sticky, output will statistically lead inflation, and the optimized parameters of rules like the Taylor rule will reflect that relationship. When demand shocks are the prevalent force behind output fluctuations, there is no dilemma for monetary policy: stabilizing output and stabilizing inflation are simultaneously achievable because they are more or less the same thing. It follows that policy can feed back on output (or its proxies) or inflation, and achieve good results either way. However when supply shocks drive cycles, inflation and output will tend to move in opposite directions, setting up a dilemma for the policymaker. Under these circumstances, responding to output and to inflation are no longer good substitutes for the purposes of

[26]This argument will clash with the intuition of readers familiar with the literature on the Great Moderation which suggests that shocks are smaller than they once were. The explanation is twofold: first, the period we are dealing with here is much shorter and has smaller residuals in both data sets. Just as important perhaps is a fallacy in the construction of the residuals in many studies that allege that shocks are smaller recently. The regressions from which these conclusions are drawn allow either a time trend or a free constant so that persistent supply-side shocks are mopped up in these terms.

minimizing losses, and responding strictly to inflation is insufficient for controlling output.

5.2.2 Three-Parameter Rules

Table 3 tests the appropriateness of using the two-parameter Taylor rule, TR, as the benchmark by considering the simple extensions noted in section 4.1.2. In particular, the second row of the table shows that the performance of the Taylor rule extended to allow an optimized parameter on the lagged instrument—that is, the inertial Taylor rule, TRI—renders only slightly better performance than the TR itself, for either vintage. Moreover, the attempt through the use of a productivity growth term in the DY* fares worse, as shown in the third line.[27] The final two lines of the table exhibit the advantage of allowing feedback on the lagged instrument relative to the YN2.

This is the one case where adding the lagged instrument to a rule that already has a nominal anchor variable and an aggregate demand term pays off in a significant way. Still, none of these rules do markedly better than the Taylor rule despite the advantage of an added parameter. I conclude that using the Taylor rule as the benchmark is not erecting a straw man. Thus, I am satisfied that focusing attention, henceforth, on two-parameter policy rules is a suitable restriction.

My goal in this paper has been to uncover policies that are both effective and robust across models. To this point, I have identified rules that, when properly specified, perform well in contexts where they should perform well; that is, they are effective. The ones that do not—the inflation-targeting rule, and nominal income and wage growth rules that include the lagged instrument as their second argument—are not candidates as robust performers. Whether the effective rules are also robust is the subject of the next section.

[27]It should be the case that the addition of an added parameter cannot do worse than the best two-parameter rule. The contradictory result shown in the table is an artifact of occasional crashes in the optimization algorithm owing to the instability of the extended rule. Still, the instability of rule is, itself, a warning against such a rule.

Table 3. FRB/US Model Performance in Stochastic Simulation (three-parameter rule optimizations, selected vintages)

$\alpha_{ijk} \rightarrow$		Anchor	Real	Added	December 1998				October 2007			
Line	**Rule↓**	i	j	k	α_i	α_j	α_k	$Loss^\dagger$	α_i	α_j	α_k	$Loss^\dagger$
1	TR	π	y	–	0.44	0.33	–	1.00	0.53	1.17	–	1.00
2	TRI	π	y	r	0.33	0.29	0.33	0.98	0.22	1.07	0.22	0.98
3	DY*	π	y	Δy^*	0.38	0.36	0.10	1.04	0.41	1.23	0.29	1.02
4	YN2	Δyn	y	–	0.02	0.43	–	1.26	0.02	1.12	–	1.06
5	YN1	Δyn	y	r	0.13	0.10	0.88	1.04	0.23	0.36	0.73	0.97

†Normalized losses. See the notes to table 2.

6. Robustness

I now turn to the principal issue, the robustness of optimized policies to model misspecification. The thought experiment is to imagine a policymaker who believes she is controlling the December 1998 economy model, but in half of the instances I discuss below, it turns out that it is the October 2007 vintage that is the true model. Those results are presented in table 4. Then, in table 5, I reverse the exercise by having our central banker assume she is controlling the October 2007 vintage, but it turns out that half of the time, it is the December 1998 vintage that is the correct model.

The same eight two-parameter rules as before are considered, for two vintages, comprising sixteen parameterizations. I subject both of these models to the same set of stochastic shocks as in the optimization exercise, for each candidate rule. As before, I am mostly interested in normalized losses where the normalization sets the loss under the appropriate optimized TR policy to unity (although I do show the absolute losses, for completeness). Before proceeding with the results, it is worth recalling, at the risk of oversimplification, that the December 1998 vintage is a model that sees the U.S. economy as being relatively stable and easy to control: rule parameterizations that are optimal for the December 1998 vintage are generally less aggressive than their October 2007 counterparts.

Beginning with the TR, where the normalized loss is unity by definition, we see that a policymaker who uses the October 2007 parameterization of that rule incurs losses about two-thirds higher than what she could have achieved had she known the true model; the Taylor rule is not particularly robust in this sense. The inflation-targeting rule, not a particularly good performer at the best of circumstances, is disastrous when misspecified, as shown on line 4. Among the top performers—at least when the true economy turns out to be the December 1998 vintage—are the price-level rule, lines 5 and 6; the change-in-unemployment rule, lines 11 and 12; and the wage growth rule that includes the gap, WN2, lines 15 and 16. Each of these rules performs at least as well as the Taylor rule when misspecified, and provides performance that is close to that of the TR

Table 4. Normalized Model Performance for Optimized Two-Parameter Rules under Stochastic Simulation* (December 1998 model vintage)

			Anchor Variables (α_i)				**Real Variables (α_j)**			**Dec. 1998 Loss**	
Line	**Rule**	**Vin.**	π	Δyn	Δw	p	y	r	Δu	**Abs.**	**Norm.**
1	TR	D98	0.44				0.33			17.6	1.00
2		O07	0.53				1.17			29.2	1.66
3	IT	D98	0.87					−0.32		25.4	1.44
4		O07	−0.30					−0.81		406.0	23.00
5	PLT	D98				8.14	0.46			18.3	1.04
6		O07				14.70	1.14			26.9	1.53
7	YN1	D98		0.20				0.93		23.7	1.35
8		O07		0.37				0.90		33.5	1.90
9	YN2	D98		0.02			0.43			22.2	1.26
10		O07		0.02			1.12		−2.52	31.0	1.76
11	DUR	D98	0.16						−3.60	21.0	1.19
12		O07	0.08					−0.41		24.3	1.38
13	WN1	D98			1.05			−0.71		25.7	1.57
14		O07			0.63					27.8	1.58
15	WN2	D98			0.72		0.39			16.2	0.92
16		O07			0.09		1.16			29.4	1.67

*Selected rules and model vintages. Average losses from 1,500 draws of eighty periods each.

when properly specified.[28] The YN2 is not far off the mark set by the optimized Taylor rule.

Table 5 turns the exercise around by considering the case where the October 2007 vintage turns out to be the correct one. Misspecification of the Taylor rule is more costly here: the deterioration relative to the best policy parameterization is 80 percent. Once again, the TRI performs very poorly, while *most* of the rules that do include feedback on the output gap—the Taylor rule, the price-level rule, one of the nominal output rules, and the change-in-unemployment rule—all perform well. The one notable exception to the conclusion that feedback on the output gap is always a good thing is the WN2, where misspecification of the rule, as in line 16, results in large losses relative to the TR and most alternatives to it. Even here, though, it seems that it is feedback on wage growth that is the key to this result, as the rules in lines 13 and 14, which respond to wage growth and the lagged instrument, but not the output gap, perform even worse. What this tells us is that while a wage growth rule can turn in a very good performance, as it does when paired with the output gap on line 15, a good calibration is critical to its performance; the rule is not robust.

The PLT turns in an even stronger performance for the October 2007 vintage than it did for the December 1998 one. This result obtains notwithstanding that the parameterizations of the two rules differ significantly: the feedback parameters on the output gap are 1.14 and 0.46. As in rational expectations models, an important contribution to economic performance under this rule is that constraining the drift in the price level anchors inflation fluctuations. In both vintages of the FRB/US model, keeping inflation in check also limits cycling in long-term expected inflation. The stability of long-term inflation expectations reinforces the stabilizing force of policy, making output stabilization less critical than would otherwise be the case.

This case contrasts sharply with the change-in-unemployment rule, DUR. For this rule, feedback on inflation itself is slight at 0.08

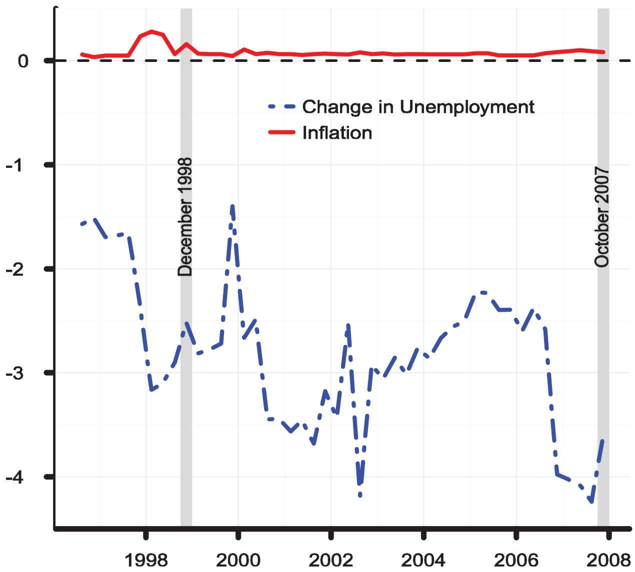
[28]If I was to take a Bayesian perspective on this and assume that the two vintages are equally probable, the average values of the losses from the PLT, the DUR, and the YN2 are all less than that of the Taylor rule, for this model vintage.

Table 5. Normalized Model Performance for Optimized Simple Rules under Stochastic Simulation* (October 2007 model vintage)

Line	Rule	Vin.	Anchor Variables (α_i)				Real Variables (α_j)			Oct. 2007 Loss	
			π	Δyn	Δw	p	y	r	Δu	Abs.	Norm.
1	TR	O07	0.53				1.17			17.7	1.00
2		D98	0.44				0.33			31.9	1.80
3	IT	O07	−0.30					−0.81		79.9	4.51
4		D98	0.87					−0.32		134.0	7.57
5	PLT	O07				14.70	1.14			17.0	0.96
6		D98				8.14	0.46			22.8	1.29
7	YN1	O07		0.37				0.90		25.2	1.42
8		D98		0.20				0.93		29.8	1.68
9	YN2	O07		0.02			1.12			18.7	1.06
10		D98		0.02			0.42		−3.60	24.6	1.39
11	DUR	O07	0.08						−2.52	15.6	0.88
12		D98	0.16					−0.71		18.9	1.07
13	WN1	O07			0.63			−0.41		104.0	5.89
14		D98			1.05					41.9	6.38
15	WN2	O07			0.09		1.16			18.3	1.03
16		D98			0.72		0.39			57.1	3.22

*Selected rules and model vintages. 1,500 draws of eighty periods each.

Figure 5. Optimized Coefficient of the Change-in-Unemployment Rule, by Model Vintage



and 0.16. But feedback on the change in the unemployment rate is vigorous: –3.60 and –2.52. Thus, aggressively tempering fluctuations in unemployment is substituting for inflation (and price-level) control. The fact that the DUR is written in the first difference of the instrument, and therefore does not depend on estimates of the equilibrium real rate of interest, is also a factor; this means that the instrument can find the right level even when a productivity shock changes what that level should be. The DUR is the one rule of which I am aware that was tested, by Orphanides and Williams (2002), in an environment that allowed for persistent, unobserved shocks to the "natural rate of interest," and was found to execute well.

The results for DUR in tables 4 and 5 suggest that it could be a robust rule. However, a closer look at the robustness of DUR is achievable by computing its optimized parameters for all vintages. The results of this exercise are shown in figure 5.

The figure shows that the coefficient on inflation, the solid line, is never much above zero, regardless of the vintage. By contrast, the coefficient on the change in the unemployment rate, the dashed line, jumps around somewhat with perhaps a slight tendency to increase, in absolute terms, over time. The range over the complete set of vintages for the coefficient on the change in the unemployment rate spans from a low of −1.4 for the November 1999 vintage to a high of −4.2 for the August 2007 vintage, considerably wider than the range encompassed by the December 1998 and October 2007 vintages, shown by the gray bars. The computations underlying figure 5 allow us to expand on the robustness analysis of tables 4 and 5 while focusing on the unemployment rate rule. This is done in table 6, where I consider the performance of the most extreme parameterizations of the rule in the two benchmark vintages.

The table shows that when either of the benchmark models is governed by the most extreme parameterization of the DUR rule, the small absolute coefficient on the (change in the) unemployment rate in the November 1999 vintage, the deterioration in control increases the loss relative to the best possible parameterization by a bit over 50 percent, as shown on line 2 of the table. The parameterization that rendered the largest coefficient on the change in the unemployment rate, the August 2007 vintage, gave coefficients that are not much different from the (chronologically close) October 2007 vintage. Thus lines 3 and 4 of the table are similar. Incremental losses, relative to the best possible DUR parameterization, of 50-some percent, are not particularly large in comparison with the results in tables 4 and 5.

7. Concluding Remarks

For central banks, the appropriate design of monetary policy under uncertainty is a critical issue. Many conferences are devoted to the subject, and the list of papers is lengthy and still growing. In nearly all instances, however, the articles, whether they originate from central banks themselves or from academia, have tended to be abstract applications. One posits an idealized model, or several models, of the economy and investigates, in some way, how misperceptions of, or perturbations to, the model affect outcomes. A good deal has been learned from these exercises, but results have tended to be specific to the environment of the chosen models. Moreover, the models themselves typically have not been representative of the models upon which central banks rely. It is difficult to know how serious a problem

Table 6. Performance of Selected Parameterizations of Change-in-Unemployment Rate Rule

Line	Rule Parameterization	Coefficients		Losses for Model			
				December 1998		October 2007	
		$\alpha_{\Delta y}$	α_{π}	Absolute	Normalized	Absolute	Normalized
1	December 1998	−2.56	0.16	20.97	1.00	26.85	1.28
2	November 1999	−1.40	0.04	33.12	1.58	31.71	1.52
3	August 2007	−4.24	0.09	26.63	1.27	21.05	1.01
4	October 2007	−3.94	0.08	25.62	1.22	20.85	1.00

model uncertainty is if one cannot give a concrete and meaningful measure of uncertainty.

This paper has cast some light on model uncertainty and the design of policy in a much different context from the extant literature. I examined forty-six vintages of the model the Federal Reserve Board staff has used to carry out forecasts and policy analysis from 1996 to 2007. And I did so in a real-time context that focuses on the real problems that the Federal Reserve faced over this period. My examination looked at a number of simple policy rules that have been marketed as "robust." In the end, I uncovered a number of useful observations. First, model uncertainty is a substantial problem. Changes to the FRB/US model over the period of study were frequent and often important in their implications. The ensuing optimized policies also differed significantly in their parameterizations. Second, many simple rules that have been touted as robust turn out to be less appealing than one might have suspected. In particular, pure inflation-targeting rules turn out not to be robust. Third, adding an instrument smoothing term to a rule that already has a nominal anchor and a real variable contributes little to the robustness and efficiency of rules, at least in the environment studied here. Fourth, notwithstanding problems of mismeasurement of output gaps, it generally pays for policy to feed back on some measure of excess demand, regardless of the nominal anchor employed elsewhere in the rule. Fifth, a case can be made for designing simple rules that minimize the use of latent variables like potential output and the equilibrium real interest rate as arguments.

References

Aoki, K. 2003. "On the Optimal Monetary Policy Response to Noisy Indicators." *Journal of Monetary Economics* 50 (3): 501–23.

Atkeson, A., and L. E. Ohanian. 2001. "Are Phillips Curves Useful for Forecasting?" *Quarterly Review* (Federal Reserve Bank of Minneapolis) 25 (1): 2–11.

Bernanke, B. S., and M. Gertler. 1999. "Monetary Policy and Asset Price Volatility." In *New Challenges for Monetary Policy,* 77–129. Kansas City: Federal Reserve Bank of Kansas City.

Blinder, A. S. 1998. *Central Banking in Theory and Practice.* Cambridge, MA: MIT Press.

Blinder, A. S., and J. L. Yellen. 2001. *The Fabulous Decade: Macroeconomic Lessons from the 1990s.* New York: Century Foundation Press.

Brainard, W. 1967. "Uncertainty and the Effectiveness of Monetary Policy." *American Economic Review* 57 (2): 411–25.

Brayton, F., A. Levin, R. Tryon, and J. C. Williams. 1997. "The Evolution of Macro Models at the Federal Reserve Board." *Carnegie-Rochester Conference Series on Public Policy* 47 (December): 43–81.

Brayton, F., and P. Tinsley, eds. 1996. "A Guide to FRB/US — A Macroeconomic Model of the United States." FEDS Paper No. 1996-42, Board of Governors of the Federal Reserve System.

Brock, W. A., S. N. Durlauf, and K. D. West. 2007. "Model Uncertainty and Policy Evaluation: Some Theory and Empirics." *Journal of Econometrics* 136 (2): 629–64.

Cecchetti, S., H. Genberg, J. Lipsky, and S. Wadhwani. 2000. *Asset Prices and Central Bank Policy.* The Geneva Report on the World Economy, Vol. 2. London: Center for Economic Policy Research.

Cimadomo, J. 2008. "Fiscal Policy in Real Time." ECB Working Paper No. 919.

Cogley, T., and T. J. Sargent. 2005. "The Conquest of U.S. Inflation: Learning and Robustness to Model Uncertainty." *Review of Economic Dynamics* 8 (2): 528–63.

Croushore, D., and T. Stark. 2001. "A Real-time Data Set for Macroeconomists." *Journal of Econometrics* 105 (1): 111–30.

Dennis, R. 2001. "Inflation Expectations and the Stability Properties of Nominal GDP Targeting." *Economic Journal* 111 (468): 103–13.

Ehrmann, M., and F. Smets. 2003. "Uncertain Potential Output: Implications for Monetary Policy." *Journal of Economic Dynamics and Control* 27 (9): 1611–38.

English, W. B., D. López-Salido, and R. J. Tetlow. 2013. "The Federal Reserve's Framework for Monetary Policy—Recent Changes and New Questions." FEDS Paper No. 2013-76, Board of Governors of the Federal Reserve System. Available at http://www.federalreserve.gov/pubs/feds/2013/201376/201376pap.pdf. Forthcoming in *IMF Economic Review.*

Garratt, A., G. Koop, E. Mise, and S. P. Vahey. 2007. "Real-time Prediction with UK Monetary Aggregates in the Presence of Model Uncertainty." Birkbeck Working Papers in Economics and Finance No. 0714, Birkbeck School of Economics, Mathematics and Statistics.

Garratt, A., and S. P. Vahey. 2006. "UK Real-Time Macro Data Characteristics." *Economic Journal* 116 (509): F119–35.

Giannone, D., L. Reichlin, and L. Sala. 2005. "Monetary Policy in Real Time." In *NBER Macroeconomics Annual 2004*, ed. M. Gertler and K. Rogoff, 161–200. Cambridge, MA: NBER and MIT Press.

Giuliodori, M., and R. Beetsma. 2008. "On the Relationship between Fiscal Plans in the European Union: An Empirical Investigation Based on Real-Time Data." *Journal of Comparative Economics* 36 (2): 221–42.

Gray, G. A., and T. G. Kolda. 2004. "APPSPACK 4.0: Asynchronous Parallel Pattern Search for Derivative-Free Optimization." Unpublished Manuscript, Sandia National Laboratories.

Jääskelä, J., and T. Yates. 2005. "Monetary Policy and Data Uncertainty." *Quarterly Bulletin* (Bank of England) 45 (4, Winter): 477.

Keynes, J. M. 1930. *The Great Slump of 1930.* 2009 Kindle edition. Orlando: Signalman.

Kimura, T., and T. Kurozumi. 2007. "Optimal Monetary Policy in a Micro-Founded Model with Parameter Uncertainty." *Journal of Economic Dynamics and Control* 31 (2): 399–431.

Kolda, T. G. 2004. "Revisiting Asynchronous Parallel Pattern Search." Unpublished Manuscript, Sandia National Laboratories.

Kreps, D. 1998. "Anticipated Utility and Dynamic Choice." In *Frontiers of Research in Economic Theory: The Nancy L. Schwartz Memorial Lectures, 1983–1997,* ed. D. P. Jacobs, E. Kalai, M. I. Kamien, and N. L. Schwartz. Cambridge: Cambridge University Press.

Levin, A. T., A. Onatski, J. C. Williams, and N. Williams. 2006. "Monetary Policy under Uncertainty in Microfounded Macroeconometric Models." In *NBER Macroeconomics Annual 2005*, ed. M. Gertler and K. Rogoff, 229–87. Cambridge, MA: NBER and MIT Press.

Levin, A., V. Wieland, and J. C. Williams. 1999. "Robustness of Simple Monetary Policy Rules under Model Uncertainty." In *Monetary Policy Rules,* ed. J. B. Taylor, 263–99. Chicago: University of Chicago Press.

McCallum, B. 1988. "Robustness Properties of a Rule for Monetary Policy." *Carnegie-Rochester Conference Series on Public Policy* 29: 173–204.

McCallum, B., and E. Nelson. 1999. "Nominal Income Targeting in an Open-Economy Optimizing Model." *Journal of Monetary Economics* 43 (3): 553–78.

Onatski, A., and N. Williams. 2003. "Modeling Model Uncertainty." *Journal of the European Economic Association* 1 (5): 1087–1122.

Orphanides, A. 2001. "Monetary Policy Rules Based on Real-time Data." *American Economic Review* 91 (4): 964–85.

Orphanides, A., R. Porter, D. Reifschneider, R. Tetlow, and F. Finan. 2000. "Errors in the Measurement of the Output Gap and the Design of Monetary Policy." *Journal of Economics and Business* 52 (1–2): 117–41.

Orphanides, A., and J. C. Williams. 2002. "Robust Monetary Policy Rules with Unknown Natural Rates." *Brookings Papers on Economic Activity* 2: 63–118.

Primiceri, G. 2005. "Time-varying Structural Vector Autoregressions and Monetary Policy." *Review of Economic Studies* 72 (3): 821–52.

Reifschneider, D. L., R. J. Tetlow, and J. C. Williams. 1999. "Aggregate Disturbances, Monetary Policy and the Macroeconomy: The FRB/US Perspective." *Federal Reserve Bulletin* (January): 1–19.

Romer, C., and D. Romer. 2002. "The Evolution of Economic Understanding and Postwar Stabilization Policy." In *Rethinking Stabilization Policy,* 11–78. Kansas City: Federal Reserve Bank of Kansas City.

Rudebusch, G. 2002. "Assessing Nominal Income Rules for Monetary Policy with Model and Data Uncertainty." *Economic Journal* 112 (479): 402–32.

Sack, B., and V. Wieland. 2000. "Interest-rate Smoothing and Optimal Monetary Policy: A Review of Recent Empirical Evidence." *Journal of Economics and Business* 52 (1–2): 205–28.

Sims, C., and T. Zha. 2006. "Were There Regime Shifts in U.S. Monetary Policy?" *American Economic Review* 96 (1): 54–81.

Söderström, U. 2002. "Monetary Policy with Uncertain Parameters." *Scandinavian Journal of Economics* 104 (1): 5–145.

Staiger, D., J. H. Stock, and M. Watson. 2001. "Prices, Wages and the U.S. NAIRU in the 1990s." NBER Working Paper No. 8320 (June).

Svensson, L. E. O., and R. Tetlow. 2005. "Optimal Policy Projections." *International Journal of Central Banking* 1 (3): 177–207.

Taylor, J. B. 1993. "Discretion Versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy* 39: 195–214.

Taylor, J. B., and V. Wieland. 2012. "Surprising Comparative Properties of Monetary Models: Results from a New Model Database." *Review of Economics and Statistics* 94 (3): 800–816.

Tetlow, R. J., and B. Ironside. 2007. "Real-Time Model Uncertainty in the United States: The Fed, 1996-2003." *Journal of Money, Credit and Banking* 39 (7): 1533–61.

Tetlow, R., and P. von zur Muehlen. 2001. "Robust Monetary Policy with Misspecified Models: Does Model Uncertainty Always Call for Attenuated Policy?" *Journal of Economic Dynamics and Control* 25 (6–7): 911–49.

Walsh, C. 2004. "Implications of a Changing Economic Structure for the Strategy of Monetary Policy." In *Monetary Policy and Uncertainty: Adapting to a Changing Economy*, 297–346. Kansas City: Federal Reserve Bank of Kansas City.

———. 2006. "Comment [on 'Monetary Policy Under Uncertainty in Micro-Founded Macroeconometric Models' by Levin, Onatski, Williams, and Williams]." In *NBER Macroeconomics Annual 2005*, ed. M. Gertler and K. Rogoff, 297–308. Cambridge, MA: NBER and MIT Press.

Williams, J. C. 2003. "Simple Rules for Monetary Policy." In *Economic Review 2003*, 1–12. San Francisco: Federal Reserve Bank of San Francisco.

On the Slope and the Persistence of the Italian Phillips Curve*

Marianna Riggi and Sergio Santoro
Bank of Italy

We investigate the determinants of inertia in Italian inflation, estimating a Phillips curve derived from a general equilibrium business-cycle model that allows for intrinsic and extrinsic sources of inflation persistence, along with trend inflation, and that encompasses both nominal and real rigidities as key factors of the output-inflation trade-off. We perform the estimation over two different sub-samples, 1981:Q1–1998:Q4 and 1999:Q1–2012:Q3, to take into account the structural break represented by the starting of the Economic and Monetary Union. We find that in the period between 1999:Q1 and 2012:Q3, the dependence of Italian inflation on its own past diminished and the slope of the Phillips curve dropped relative to the years before 1999. The latter is a consequence of increased strategic complementarity in price setting, due in turn to higher sensitivity of demand elasticity to firms' relative prices, on top of lower trend inflation and an increase in the average duration of prices.

JEL Codes: E31, E32.

1. Introduction

During the Great Recession inflation in advanced countries hardly responded to conditions in product and labor markets. According to many economists,[1] based on past experiences and given the depth and the duration of the worldwide recession, advanced economies should have experienced severe disinflation—perhaps even deflation.

*We wish to thank the editor, three anonymous referees, Eugenio Gaiotti, Roberto Sabbatini, and Francesco Zollino for their very helpful suggestions. The views expressed here do not necessarily reflect those of the Bank of Italy.

[1]See section 2 for a literature review.

Hall (2011) called for a fundamental reconsideration of theories in which inflation depends on a measure of slack, reading the recent experience as a contradiction to the axiomatic relationship between slack and declining inflation and concluding that inflation behaves in a nearly exogenous fashion. A debate has emerged to find possible tweaks to the traditional Phillips curve and explain why extreme economic slump has done little to reduce inflation in most advanced economies.

In this paper we focus on Italy. After the outburst of the sovereign debt crisis in the euro area, GDP in Italy contracted bluntly, by almost 5 percent from mid-2011 to the end of 2013, more than the euro-area average. However, at the beginning of this prolonged recession, inflation remained stubbornly high, above 3 percent year on year until the last months of 2012. Although the rise in indirect taxes contributed by around 1 percentage point, even the price index computed net of the increase in indirect taxation grew at a faster pace than in the euro area. In 2013 inflation started moderating, and it dropped below 1 percent in the second half of the year. However, core inflation (i.e., net of food and energy prices) remained hovering around 1 percent, despite an unprecedented contraction of domestic demand. This outturn suggests that in the short run the relationship between economic activity and price dynamics (i.e., the Phillips curve) might be relatively weak in Italy, hence justifying such a slow and, so far, moderate response of inflation to the collapse of output.

Nevertheless, this reduced-form evidence should be considered with caution, since it is plagued by the Lucas critique, as it might be driven by monetary policy. Moreover, various factors may lie behind a slow adjustment of inflation. Some of them are associated with what Altissimo, Ehrmann, and Smets (2006) define as "extrinsic persistence," namely that inherited from persistent fluctuations in the determinants of inflation such as marginal costs or the output gap. Additionally, inflation can show "intrinsic persistence," if it depends on its own past. In a New Keynesian framework the latter might be generated by different channels, like the assumption of indexation or rule-of-thumb behavior on the part of the price or wage setters. Finally Altissimo, Ehrmann, and Smets (2006) highlight that if expectations are not rational, there might be persistence due to the formation of inflation expectations ("expectations-based persistence").[2]

We want to document the slope of the Italian Phillips curve and identify the source of persistence of Italian producer price inflation over two periods: 1981–98 and 1999–2012.[3] To do so, we estimate a New Keynesian structural model of the Italian inflation that allows for both extrinsic and intrinsic persistence. To model the former, we draw on the more recent literature on New Keynesian monetary economics that has emphasized the role of the following factors: the frequency of price revisions, the economy's returns to scale, and the sensitivity of the elasticity of demand to the firm's relative price. The latter gives rise to strategic complementarities in price setting. In addition, we allow for positive trend inflation, needed given our strong empirical focus. Intrinsic persistence is instead due to partial indexation of prices, which introduces a backward-looking element in inflation determination.

There is an ample literature on the estimation of the Phillips curve. In recent years, following the seminal contribution of Galí and Gertler (1999), many papers have adopted the New Keynesian framework and, estimating a single-equation model via the GMM, have investigated the importance of intrinsic inertia to account for the observed inflation dynamics. Benigno and López-Salido (2006) and Rumler (2007) apply this technique to several euro-area countries, including Italy, finding that in a sample which covers mainly the period before 1999 in Italy there is a significant role for "backward-lookingness" in inflation, and thus for intrinsic inflation persistence. In these papers the only source of extrinsic persistence is the existence of nominal rigidities; instead, as mentioned above, we allow also for the presence of strategic complementarities in price setting, following the formulation introduced in Sbordone (2010). A different approach is implemented by Gaiotti (2010), who uses micro data to assess the role of globalization for the flattening of the Phillips curve in Italy.

[2]See Molnár and Santoro (2014) for the implications of non-rational beliefs on monetary policy.

[3]We follow most of the theoretical New Keynesian literature in concentrating on the link between real unit labor cost and producer price inflation rather than consumer price inflation.

Rather than relying on a single-equation estimation, we estimate the deep parameters that determine the slope and the persistence of the Phillips curve generated by our model using full-information Bayesian techniques. This allows us to disentangle the role played by the different factors in the relationship that links the dynamics of domestic inflation to its determinants. We use quarterly data on industrial producer price inflation,[4] GDP, short-term interest rate, and real wages over two distinct sub-samples: 1981:Q1–1998:Q4 and 1999:Q1–2012:Q3. The rationale for splitting the sample in connection with the start of the Economic and Monetary Union is the need to account for the above-mentioned importance of monetary policy conduct in shaping the Phillips curve.

In the empirical implementation, we adopt a measure of unit labor cost as the relevant determinant of producer price changes, instead of an ad hoc output gap. In the class of model we consider, this choice is innocuous, since there is an approximate log-linear relationship between the two variables; moreover, we avoid the pitfall of using measures of the output gap constructed with some type of filters that are not consistent with the theoretical structure of the model.[5]

We find significant changes in the Phillips curve in the more recent years. More in detail, our model implies a Phillips curve of the following form: $\pi_t^p = \lambda_1 \pi_{t-1}^p + \lambda_2 \mathbb{E}_t \left[\pi_{t+1}^p\right] + \lambda_3 mc_t + \lambda_4 \mathbb{E}_t \phi_{t+1} + \lambda_5 \mathbb{E}_t \varphi_{t+1}$, where π_t^p denotes price inflation, mc_t is real unit labor cost, and ϕ_{t+1} and φ_{t+1} are auxiliary variables. We get that the slope of the Phillips curve (namely, the short-term sensitivity of inflation to marginal costs, λ_3) has dropped sharply, from 0.74 to 0.05.

According to our estimates, the increased strategic complementarity in price setting, due to its turn to higher sensitivity of demand elasticity to firms' relative prices, has played an important role in determining the vanishing trade-off between producer price inflation and unit labor cost. In other words, the story suggested by our estimates is the following.

[4]Hence we abstract from the service sector.

[5]See Galí and Gertler (1999). They also show that estimating the New Keynesian Phillips curve using filtered GDP data as a proxy for the output gap delivers misleading results.

Whereas in the pre-1999 period the price elasticity of demand was almost constant, after 1999 the elasticity of substitution between a given variety and others increased in the firm's good's relative price, leading to strategic complementarities in price setting and to a flatter Phillips curve. Indeed, when a repricing firm faces a higher unit labor cost, say due to an economic boom, the firm will temper its price increase relative to the pre-1999 period because this would result in a more elastic demand curve than for those firms whose relative price declines as a result of price fixity. Symmetrically, during recessions firms are more reluctant to reduce their price relative to the pre-1999 period, as they would face a less elastic demand curve than their competitors whose relative price increases as a result of price rigidity. In other words, as Basu (2005), Dotsey and King (2005), and Klenow and Willis (2006) show, a price elasticity of demand that increases with the firm's relative price generates a smoothed version of a "kink" in the demand curve facing a given firm. Indeed, it implies that consumers flee from individual items with high relative prices, but do not flock to inexpensive ones, creating "rigidity" in the relative price a firm wants. Hence, the higher sensitivity of the demand elasticity to the firm's relative price (and the consequent increase in strategic complementarities in price setting) in the post-1999 period has weakened the short-term relationship between economic activity and price dynamics in Italy and explains the slow adjustment of inflation during a severe and long-lasting recession.[6]

Our model is not designed to capture the primitive sources driving this increase in strategic complementarities; however, in a similar framework Sbordone (2010) points out that it can be associated with an increase in market competition. This seems to be consistent with some fundamental changes in the context surrounding Italy: Brandolini and Bugamelli (2009) argue that the shift in the technological paradigm, ushered in by the new information and communications technologies (ICT); "globalization," that is, the global integration of the real and financial markets; and the process of European integration had as a common consequence a strong and sharp increase in competitive pressure.

[6]Let us recall that this is a business-cycle model; hence it is silent on the long-run relationship between producer prices and labor cost.

On top of increased strategic complementarities, we estimate an increase in the degree of price stickiness that flattens the Phillips curve. According to our results, the average duration of a price is nearly 1.7 quarters in the first sub-sample and 2.9 in the second one, consistent with the common wisdom that as inflation has decreased over time, one would expect price setters to change prices less often.

The vanishing trade-off between producer price inflation and unit labor cost also stems from the decrease in trend inflation, which we calibrate to match the decline in the average sample inflation. Importantly, whereas in a Dixit-Stiglitz world the slope of the New Keynesian Phillips curve becomes steeper under lower trend inflation (Ascari 2004), the presence of strategic complementarities inverts the sign of the derivative: the Phillips curve flattens as the trend inflation rate declines.

The degree of intrinsic persistence λ_1 has decreased in the second sub-sample (from 0.45 to 0.18), suggesting that the observed reduced-form persistence of inflation in recent years cannot be attributed to intrinsic inflation persistence but rather to an increase in extrinsic persistence due to stronger real rigidities.

A flatter Phillips curve involves a higher sacrifice ratio than otherwise, i.e., a longer spell of GDP below its natural level for every desired reduction in inflation. However, it also implies that an overheated economy will tend to induce a milder rise in inflation and, vice versa, reduces the risk of deflation in the face of severe downturns.

The paper is organized as follows. Section 2 indicates how our study relates to the literature. Section 3 presents the theoretical model. Section 4 provides a discussion of the role of nominal rigidities, strategic complementarities, backward indexation, and trend inflation for the Phillips curve implied by our theoretical framework. Section 5 briefly summarizes the Bayesian technique we employ. Section 6 describes data and prior distributions. Section 7 discusses our results and section 8 concludes.

2. Related Literature

The absence of a severe disinflation during the recent deep worldwide recession was not peculiar to Italy. Since the financial crisis of 2008–9, extreme economic slack has done little to reduce inflation in most advanced economies, insomuch that Hall (2013) reads the recent experience as a contradiction to the fundamental macroeconomic axiom that inflation declines during periods of economic weakness. In September 2010 John Williams stated, "The surprise [about inflation] is that it's fallen so little, given the depth and duration of the recent downturn. Based on the experience of past severe recessions, I would have expected inflation to fall by twice as much as it has." The missing disinflation between 2009 and 2011 is particularly striking when compared with the strong deflation that hit the United States during the Great Depression (cumulative deflation between 1930 and 1932 was nearly 25 percent). Ball and Mazumder (2011) document that when Phillips curves estimated over 1960–2007 are used to predict inflation over 2008–10, a puzzle emerges, as inflation should have fallen by much more than it did. Fostered by this evidence, a large literature has emerged to find possible tweaks to the traditional Phillips curve and explain why inflation has fallen so little in spite of the severity and duration of the recent crisis.

Ball and Mazumder (2011) show that the puzzle can be solved with two modifications of the Phillips curve, both suggested by theories of costly price adjustment: first by measuring core inflation with the median CPI inflation rate, and second by allowing the slope of the Phillips curve to change with the level and variance of inflation.[7]

According to Bernanke (2010), the credibility of modern central banks has succeeded in relegating high inflation and high deflation as very unlikely outcomes in people's conviction and, thus, in stabilizing actual inflation through expectational channels. However, while there is evidence that inflation expectations in the United States and in the euro area have indeed become more anchored over time (Williams 2006), Coibion and Gorodnichenko (2013) convincingly show that this "anchored expectations" hypothesis is not sufficient to explain the full extent of the missing disinflation in the United States between 2009 and 2011, as the latter is still present in the data even after conditioning on the "anchored" expectations of professional forecasters. Coibion and Gorodnichenko (2013) propose a novel explanation based on the idea that household forecasts are likely to be a better proxy for firm inflation expectations (i.e., the ones relevant for pricing decisions and thus

[7]The second tweak is consistent with our results.

for the Phillips curve) than either professional or backward-looking forecasts. When household inflation expectations—measured by the Michigan Survey of Consumers—are considered in an expectations-augmented Phillips curve, then the puzzle of the missing disinflation in the United States since 2009 is solved. Indeed, while households' inflation expectations rose sharply since 2009, pushed by oil price increases, other measures of inflation expectations, such as those from financial markets or professional forecasters, have stayed stable in the neighborhood of 2 percent over the same period.[8]

Studying the Swedish case, Svensson (2013) points out that if inflation expectations are irrationally anchored at the inflation target even when average inflation is systematically lower than the target, the long-run Phillips curve becomes downward sloping and the undershooting of the inflation target brings higher average unemployment than if average inflation had been kept on target.

Other authors focus on the wage formation process as the driving force behind the lack of disinflation. Among them, Daly, Hobijn, and Lucking (2012) point to downward nominal wage rigidity as an important factor that has shaped the dynamics of inflation during and after the last three U.S. recessions. In fact, the fraction of workers receiving zero wage changes in the U.S. economy increases around business-cycle downturns and has risen to historical highs since the 2007 recession. The resistance to reducing wages, especially at low levels of inflation, might have bent the short-run Phillips curve.

Finally, the interpretation favored by the International Monetary Fund's (2013) analysis is that, on the top of more firmly anchored long-term inflation expectations, the relation linking the rate of change in prices to the level of economic activity in advanced countries is considerably flatter today than in the past. By estimating

[8]Coibion and Gorodnichenko (2013) show that more than half of the historical differences in inflation forecasts between households and professionals can be accounted for by oil price dynamics, and that the run-up in oil prices since 2009 can fully explain the rise in household inflation expectations since then. The authors conjecture that households adjust their inflation forecasts more in response to oil price changes than professional forecasters because gasoline prices are among the most visible prices to consumers. Consistently, they show that according to data from the Michigan Survey of Consumers, inflation forecasts of those who spend more money on gasoline (in dollar terms) react more in response to oil price variations than expectations of those who spend less money on gasoline.

an unemployment-based Phillips curve for twenty-one advanced economies, the IMF's (2013) study concludes that the average slope of the Phillips curve has flattened as inflation rates declined and suggests, as an explanation, that the prices' adjustment costs may induce firms to vary prices less frequently when inflation is lower (Ball, Mankiw, and Romer 1988 and Klenow and Malin 2010). On the other hand, the evidence on the role of globalization in affecting the slope of the Phillips curve is either inconclusive or negative (Ball 2006; Gaiotti 2010).

3. The Model

We consider an environment of monopolistically competitive firms each producing a differentiated good. The price adjustment rule is time dependent, following the formalism proposed in Calvo (1983). With respect to a basic dynamic New Keynesian setup, the distinctive features of our theoretical framework can be summarized as follows.

We assume a trend component in technology, so that data do not need to be detrended before estimation and the dynamics of the model is evaluated with respect to a balanced growth path. To improve the empirical performance of the model, we consider positive trend inflation (on the empirical relevance of trend inflation, see Cogley and Sbordone 2008).[9] In the spirit of Galí and Gertler (1999), we augment the Calvo model in price setting by the assumption that

[9]The canonical New Keynesian sticky-price model, which has emerged as the workhorse for monetary policy analysis, hinges on inflation being a stationary variable. In recent years, there has been a great deal of research focusing on inflation persistence. Some empirical works question the hypothesis of inflation being I(0) and find that log prices are I(2) and that inflation therefore is I(1). A few of these are Johansen (1992), Bardsen, Jansen, and Nymoen (2004), O'Reilly and Whelan (2005), Fanelli (2008), and Mavroeidis, Plagborg-Møller, and Stock (2013). The empirical evidence on the stationarity of inflation is quite mixed. For instance, Zivot and Andrews (1992) and Lumsdaine and Papell (1997), among others, conclude that inflation rates are stationary. Concerning European countries, Culver and Papell (1997) apply time-series unit-root tests to thirteen OECD countries and find overwhelming evidence in favor of inflation being I(0). Here we stick to the hypothesis of inflation being a stationary variable consistent with the standard New Keynesian model and with a successful implementation of inflation targeting. However, we appropriately take into account the empirical and theoretical relevance of a positive steady inflation rate.

prices that are not reoptimized are partially indexed to past inflation rates. As stressed by Galí and Gertler (1999), the estimation of the degree of indexation allows to measure the residual inertia that the forward-looking Phillips curve leaves unexplained.[10] We allow for variable demand elasticity (Kimball 1995) with the aim to take into account the role of strategic complementarity in shaping the relationship that links the dynamics of inflation to unit labor cost. Four structural shocks are considered in order to avoid stochastic singularity and achieve an exact identification of the model: a monetary policy shock, a technology shock, and two preference shocks, one intertemporal and one intratemporal.[11]

3.1 Preferences

We consider a continuum of households uniformly distributed on the unit interval. The household is the relevant decision unit and has an objective function given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \varsigma_t \beta^t \left\{ U\left(C_t\left(j\right)\right) - \chi_t V\left(N_t\left(j\right)\right) \right\}, \tag{1}$$

where $C_t(j)$ denotes household's j consumption; $N_t\left(j\right) \in [0,1]$ indicates the fraction of household members who are employed; and ς_t and χ_t are two preference shocks which are assumed to follow stationary first-order autoregressive (AR(1)) processes $\varsigma_t = \varsigma_{t-1}^{\rho_\varsigma} e^{\varepsilon_t^{\varsigma_t}}$ and $\chi_t = \chi_{t-1}^{\rho_\chi} e^{\varepsilon_t^{\chi}}$, respectively.

We specify the household's period utility to be given by

$$U\left(C_t\left(j\right)\right) \equiv \log C_t\left(j\right) \tag{2}$$

$$V\left(N_t\left(j\right)\right) \equiv \frac{N_t^{1+\phi}(j)}{1+\phi}. \tag{3}$$

The period budget constraint takes the form

$$P_t C_t\left(j\right) + Q_t B_t\left(j\right) = B_{t-1}\left(j\right) + W_t N_t(j) + \Pi_t,$$

[10] Galí and Gertler (1999) suggest that adding rule-of-thumb price setters allows to measure the departure from the baseline forward-looking model in the spirit of the way that Campbell and Mankiw (1989) use rule-of-thumb consumers to test the life-cycle/permanent-income hypothesis.

[11] See below for more details.

where P_t is the price index for goods; W_t is the nominal wage; Π_t are profits; Q_t is the price of a one-period riskless bond, paying one unit of currency; and B_t denotes the quantity of that bond purchased in period t.

We assume a flexible variety aggregator à la Kimball (1995), which allows for the possibility that firms face price elasticity of demand which is increasing in firms' relative prices. Whereas in the Dixit-Stiglitz preferences the elasticity of substitution between a given variety and others is constant, in Kimball's world the elasticity of substitution between differentiated goods is decreasing in the relative quantity consumed of the variety, implying that firms' desired markup is decreasing in their relative price. The consumption aggregate is defined by

$$\int_{\Omega} \psi\left(\frac{C_t(i)}{C_t}\right) di = 1, \tag{4}$$

where $\psi(\cdot)$ is an increasing, strictly concave function, and Ω is the set of all potential goods produced. The standard constant elasticity of substitution (CES) preferences are nested within this specification, and the Kimball aggregator reduces to the Dixit-Stiglitz when $\psi\left(C_t(i)/C_t\right) = \left(C_t(i)/C_t\right)^{\frac{\epsilon-1}{\epsilon}}$. In order to allocate its consumption expenditures among the different goods, the household maximizes the consumption index C_t for any given level of expenditures $\int_0^1 P_t(i)\,C_t(i)\,di$. The solution to that problem yields the set of demand equations $P_t(i) = \frac{1}{\Lambda_t C_t}\psi'\left(\frac{C_t(i)}{C_t}\right)$ for each $i \in [0,1]$, where Λ_t is the Lagrangian multiplier for constraint (4). Accordingly, we can write the demand curve for good i as

$$C_t(i) = C_t \psi'^{-1}\left(\frac{P_t(i)}{P'_t}\right), \tag{5}$$

where $P'_t \equiv \frac{1}{\Lambda_t C_t}$ for any set of prices $\{P_t(i)\}$. We define the price index as the cost of a unit of the composite good:

$$P_t = \frac{1}{C_t}\int_0^1 P_t(i)\,C_t(i)\,di = \int_0^1 P_t(i)\,\psi'^{-1}\left(\frac{P_t(i)}{P'_t}\right). \tag{6}$$

Following Dotsey and King (2005) and Sbordone (2010), we adopt a functional form that implies $P'_t = \left[\int_0^1 P_t(i)^{1-(1+\eta)\epsilon}\,di\right]^{\frac{1}{1-(1+\eta)\epsilon}}$,

$P_t = \frac{1}{1+\eta} P_t' + \frac{\eta}{1+\eta} \int_0^1 P_t(i)\, di$. Hence, the relative demand for good i (5) is

$$\frac{C_t(i)}{C_t} = \frac{1}{1+\eta} \left[\left(\frac{P_t(i)}{P_t'} \right)^{-(1+\eta)\epsilon} + \eta \right]. \tag{7}$$

Clearly the Dixit-Stiglitz preferences are nested within this specification for $\eta = 0$.

The optimal consumption/savings and labor supply decisions are described by the following conditions:

$$Q_t = \beta \mathbb{E}_t \frac{\varsigma_{t+1}}{\varsigma_t} \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \tag{8}$$

$$\frac{W_t}{P_t} = \chi_t N_t^{\phi} C_t. \tag{9}$$

3.2 Technology

There is a continuum of firms distributed uniformly on the unit interval. Each firm is indexed by $i \in [0,1]$ and produces a differentiated good with a technology

$$Y_t(i) = Z_t N_t^{1-\alpha}(i). \tag{10}$$

Z_t is an aggregate technology index which follows the trend-stationary process

$$Z_t = \gamma^t A_t, \tag{11}$$

where γ is the deterministic growth rate of the economy and A_t is a stationary AR(1) process, i.e., $A_t = A_{t-1}^{\rho_A} e^{\varepsilon_t^A}$.

3.3 Price Setting

Each firm may reset its price only with probability $(1-\theta)$, independently of the time elapsed since the last adjustment (Calvo 1983). With probability θ the firm adjusts its price mechanically according to $P_t(i) = (\gamma_{p,t-1})^{\tau_p} P_{t-1}(i)$, where $\gamma_{p,t-1} \equiv \left(\frac{P_{t-1}}{P_{t-2}} \right)$

denotes last-period inflation. We denote with $\overline{\Pi}$ steady-state inflation.[12]

A firm reoptimizing in period t will choose the price P_t^* by solving the following maximization problem:

$$\max_{P_t} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_t \left\{ \Lambda_{t,t+k} \left(P_t^* \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\tau_p} Y_{t+k/t} - \Psi_{t+k} \left(Y_{t+k/t} \right) \right) \right\} \tag{12}$$

subject to the sequence of demand constraints (7),

$$Y_{t+k/t} = \frac{1}{1+\eta} \left[\left(\frac{P_t^* \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\tau_p}}{P'_{t+k}} \right)^{-(1+\eta)\epsilon} + \eta \right] Y_{t+k}. \tag{13}$$

Combining the first-order conditions for this problem with the aggregate price index and log-linearizing, we get the following system of equations that characterizes the generalized Phillips curve under trend inflation, strategic complementarities, and backward indexation:

$$\begin{aligned}
\pi_t = {} & \frac{\tau_p (1+kDD)}{1+kDD+\widetilde{\beta}\tau_p} \pi_{t-1} + \frac{\widetilde{\beta}}{1+kDD+\widetilde{\beta}\tau_p} \mathbb{E}_t (\pi_{t+1}) \\
& + \frac{k}{1+kDD+\widetilde{\beta}\tau_p} \left(\widetilde{w_t^r} - \widetilde{mpn}_t \right) + \frac{\omega_1}{1+kDD+\widetilde{\beta}\tau_p} \mathbb{E}_t \widehat{\phi}_{t+1} \\
& + \frac{\omega_2}{1+kDD+\widetilde{\beta}\tau_p} \mathbb{E}_t \widehat{\varphi}_{t+1} \\
\widehat{\phi}_t = {} & \left[1 - \beta\theta\Pi^{(1+\eta)\epsilon(1-\tau_p)} \right] \left\{ \left(\widetilde{w_t^r} - \widetilde{mpn}_t \right) + \left[(1+\eta)\epsilon BB - DD \right] \Delta_t \right\} \\
& + \beta\theta\overline{\Pi}^{(1+\eta)\epsilon(1-\tau_p)} \mathbb{E}_t \left[\widehat{\phi}_{t+1} + (1+\eta)\epsilon\Delta_{t+1} \right] \\
\widehat{\varphi}_t = {} & \beta\theta\overline{\Pi}^{-(1-\tau_p)} \mathbb{E}_t \left(\widehat{\varphi}_{t+1} - \Delta_{t+1} \right),
\end{aligned} \tag{14}$$

[12] If one imposed full price indexation to past inflation, the theoretical relevance of a positive average inflation rate would be muted, as in this extreme case there would not be price dispersion in the steady state (see Ascari and Sbordone 2013).

where π_t denotes inflation, $\widetilde{w_t^r}$ the detrended real wage, and $\widetilde{mpn}_t$ the marginal product of labor, log-linearized around the stationarized steady state. Also we have denoted $\Delta_t \equiv \pi_t - \tau_p \pi_{t-1}$. $\widehat{\phi}_t$ and $\widehat{\varphi}_t$ are auxiliary variables. The coefficients are convolutions of parameters, inter alia, trend inflation $\overline{\Pi}$, price indexation τ_p, and the degree of strategic complementarities η.[13] See the appendix for details.

3.4 Monetary Policy

The model is closed by assuming the following forward-looking rule linking the interest rate to economic activity and inflation:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho_r} \left[\left(\frac{\mathbb{E}_t\left(\Pi_{t+1}\right)}{\overline{\Pi}}\right)^{\phi_\pi} \left(\widetilde{Y}_t\right)^{\phi_y}\right]^{1-\rho_r} \mu_t, \qquad (15)$$

where $\overline{R}$ is the steady-state nominal gross rate, $\widetilde{Y}_t$ is the cyclical component of GDP obtained by detrending Y_t with the level of technology γ^t, and μ_t is a monetary policy shock, which is assumed to follow the stationary $AR(1)$ process $\mu_t = \mu_{t-1}^{\rho_\mu} e^{\varepsilon_t^\mu}$.

A caveat is required. Starting from 1999, monetary policy has been set uniformly by the European Central Bank (ECB) for the euro area as a whole. Equation (15) should be read as a positive, rather than normative, relationship capturing the correlation of the interest rate to the country-specific economic conditions.

4. The Phillips Curve

The Phillips curve implied by our theoretical model can be written as

$$\pi_t = \lambda_1 \pi_{t-1} + \lambda_2 \mathbb{E}_t\left[\pi_{t+1}\right] + \lambda_3 \left(\widetilde{w_t^r} - \widetilde{mpn}_t\right) + \lambda_4 \mathbb{E}_t \phi_{t+1} + \lambda_5 \mathbb{E}_t \varphi_{t+1}.$$

The dynamics of inflation depends on three major driving forces: past realized values of inflation, the expectations of future inflation, and the real unit labor cost. The latter affects price dynamics through several channels.

---

[13] Our Phillips curve is an extension of the one derived in Ascari and Ropele (2007, 2009) to the case in which the Dixit-Stiglitz constant elasticity does not necessarily hold.

- *Nominal rigidities.* The longer prices are kept unchanged, the flatter the Phillips curve. Indeed, the smaller the frequency of price changes, the more nominal disturbances translate into real effects rather than aggregate inflation.
- *The degree of indexation to past inflation.* The larger the degree of indexation to past inflation, the flatter the Phillips curve. The reason is that a smaller fraction of inflation dynamics is due to movements in real unit labor cost, since past inflation exerts a mechanical pressure on contemporaneous inflation.
- *The degree of trend inflation.* One established result in the macroeconomics of trend inflation (see Ascari and Sbordone 2013, among others) is that the Phillips curve becomes steeper under lower steady inflation. Such a result ceases to hold when one leaves the Dixit-Stiglitz world (see figure 1): if the elasticity of substitution between a given variety and others is increasing in the firm's good's relative price, the slope of the curve flattens when trend inflation falls, consistently with most economists' priors (see Shirota 2007).
- *The sensitivity of the marginal costs to the firm's level of production.* The higher the sensitivity of the marginal costs to the level of production, the flatter the Phillips curve. The intuition is as follows. When a firm faces decreasing returns to scale, the marginal cost is increasing in its own output. Hence, in the face of an increase in $\left(\widetilde{w_t^r} - mpn_t\right)$, the desired price increase is smaller because the firm takes into account the decline in marginal cost due to the loss in demand associated with the price increase.
- *The steady-state sensitivity of the firm's own output demand to its relative price.* The higher the steady-state elasticity of demand, the larger the loss in demand incurred for a price increase, the smaller the desired price increase for any given rise in $\left(\widetilde{w_t^r} - mpn_t\right)$, and the flatter the Phillips curve.
- *The sensitivity of the elasticity of substitution between differentiated goods to the relative quantity consumed of the variety.* When the elasticity of substitution between differentiated goods is decreasing in the relative quantity consumed of the variety, firms face a price elasticity of demand that is

increasing in their good's relative price. This makes the desired markup decreasing in firms' relative price. The larger the sensitivity of the elasticity of substitution to the relative price (the more negative is η), the flatter the Phillips curve. Indeed, when the elasticity of demand is increasing in the relative price, firms are reluctant to change their price, as they would face a more elastic demand curve than firms whose relative price declines as a result of price fixity.

Following the literature (Woodford 2003; Sbordone 2010), we call the last three components "strategic complementarity" channels.

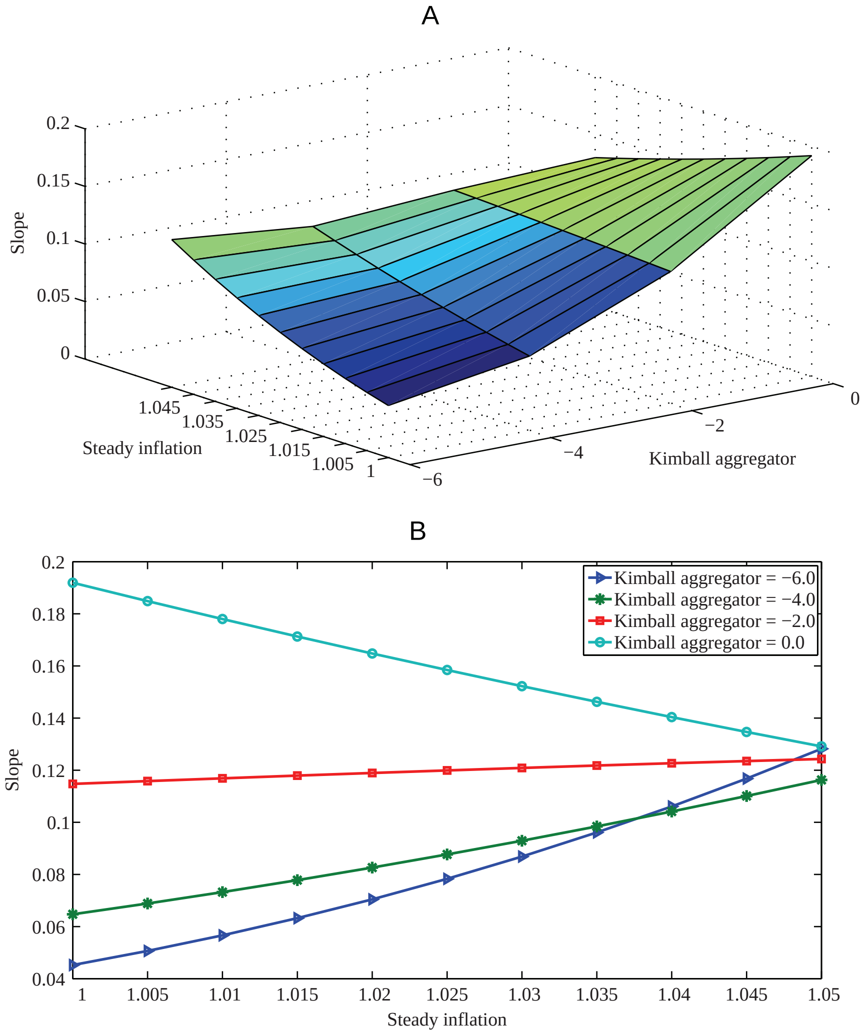
Figures 1, 2, 3, and 4 show the slope of the Phillips curve under different combinations of η and $\overline{\Pi}$, η and θ, τ_p and θ, and $(1-\alpha)$ and θ.

In order to evaluate the role of nominal rigidities and strategic complementarity in determining the slope of the Phillips curve, we implement a Bayesian Markov chain Monte Carlo (MCMC) estimation procedure in the spirit of Schorfheide (2000), Smets and Wouters (2003, 2007), and Fernandez-Villaverde and Rubio Ramirez (2004).

5. Bayesian Estimation

When dealing with the estimation of dynamic general equilibrium models, the performances of the full-information maximum-likelihood (FIML) estimator may be significantly compromised. Indeed, the mapping of structural parameters to the coefficients of the reduced form of the model is highly non-linear and non-identification is frequent, as different sets of parameters may yield nearly the same value for the likelihood function (Canova and Sala 2009). A viable solution would be to use a constrained FIML estimator that restricts the estimates within a reasonable range. However, recent developments rely on Bayesian estimation, where restrictions (priors) are defined in terms of probability distributions and the posterior distribution for the model parameters is obtained by nesting the formalized prior distribution for the vector parameters $\xi \in \Xi$ and the likelihood of the data. The posterior distribution can be read as a weighted average of prior non-sample information and the

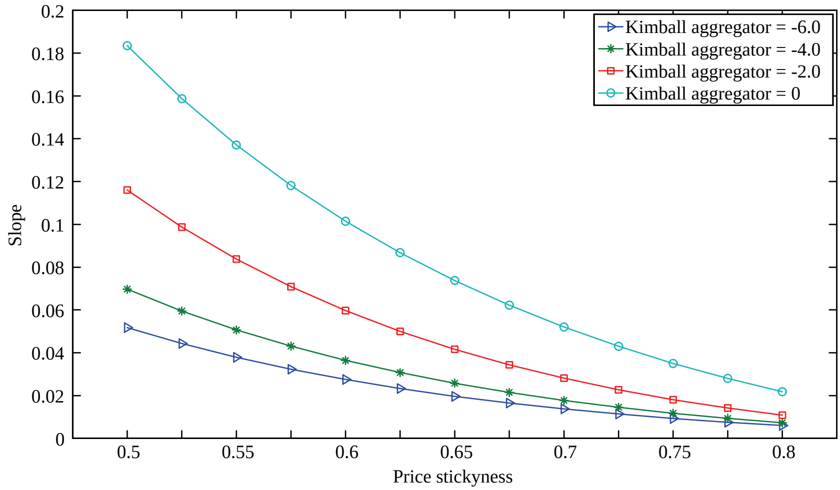
Figure 1. Trend Inflation, Kimball Aggregator, and the Slope of the Phillips Curve



Notes: Panel A: On the x-axis η. On the y-axis $\overline{\Pi}$. Panel B: On the x-axis $\overline{\Pi}$. Each curve is drawn under a different calibration for η.

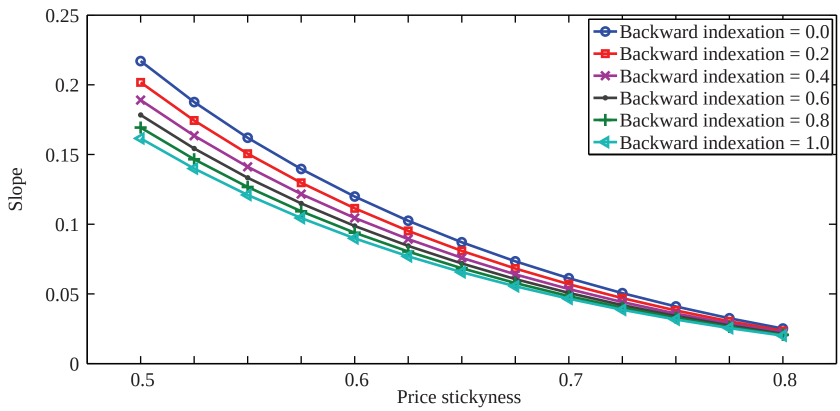
conditional distribution, where the weights are inversely related to the variance of the prior distributions and the variance of the sample information, respectively.

Figure 2. Price Stickiness, Kimball Aggregator, and the Slope of the Phillips Curve



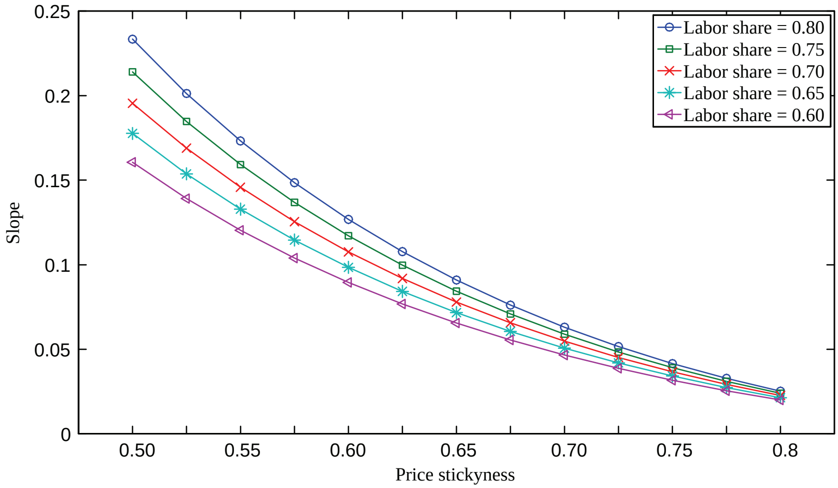
Notes: On the x-axis θ. Each curve is drawn under a different calibration for η.

Figure 3. Price Stickiness, Backward Indexation, and the Slope of the Phillips Curve



Notes: On the x-axis θ. Each curve is drawn under a different calibration for τ_p.

Figure 4. Price Stickiness, Returns to Scale, and the Slope of the Phillips Curve



Notes: On the x-axis θ. Each curve is drawn under a different calibration for $(1-\alpha)$.

More in detail, let $P(\xi, M)$ denote the prior beliefs on parameters ξ given model M and let $P(X_T/\xi, M)$, $X_T = \{x_t\}_{t=1}^{T}$ denote the conditional distribution (likelihood). By using the Bayes rule, the posterior density $P(\xi/X_T, M)$ can be written as

$$P(\xi/X_T, M) = \frac{P(X_T/\xi, M)P(\xi, M)}{P(X_T, M)}. \tag{16}$$

Following the literature, we get the Bayesian posterior estimates by using the Kalman filter to form the likelihood function and the Metropolis-Hastings algorithm for Monte Carlo integration (three chains of 1,000,000 draws) to optimize the posterior density function. We formally check whether estimation is possible or whether there are serious identification issues by verifying the necessary and sufficient conditions for local identification discussed by Iskrev (2010b) for the parameters declared in the prior definition at the prior mean; see the appendix for details.

6. Data and Prior Distribution

Our model is estimated by using Italian quarterly data over two sample periods: 1981:Q2–1998:Q4 and 1999:Q1–2012:Q2. We consider four time series: the log-differences of real GDP and of the real wage,[14] the short-term interest rate, and the percent change in the producer price index as a measure of inflation. As argued before, the rationale for splitting the sample in connection with the start of the Economic and Monetary Union is the need to account for the importance of monetary policy conduct in shaping the Phillips curve. In order to verify the presence of a structural break in the correlation among our observed series, we apply a Chow test to the VAR representation of inflation with different lags, and the test always rejects the null hypothesis that there is no structural break in 1999:Q1 at the significance level of 1 percent.

In order to enhance estimation of the key structural parameters, we impose the following dogmatic priors. The discount factor β is fixed at 0.99 and the Frisch elasticity on labor supply $1/\phi$ is set at 1, a standard calibration for macroeconomic models. The "share" parameter on labor in the production function $(1-\alpha)$ is fixed at 2/3 (consistent with computation in Giordano and Zollino 2013). We set $\epsilon = 6$, consistent with Dotsey and King (2005).[15]

Our sample data feature an average quarterly GDP growth rate of almost 0.5 percent in the pre-1999 period and 0.2 percent in the post-1999 period. We use this information to calibrate the steady-state value of productivity growth γ. We calibrate steady inflation to match the observed decline in the average annual sample producer price inflation, which is nearly 4.9 percent in the first sample and 2.4 percent in the second sample. All remaining parameters are estimated.

[14] The real wage is obtained by deflating earned income in manufacturing with the consumer price index.

[15] As discussed in the appendix, in order to check formally whether estimation is possible or whether there are serious identification issues, we verify the necessary and sufficient conditions for local identification discussed by Iskrev (2010b) for the parameters declared in the prior definition at the prior mean. When we include ϵ in the set of the parameters to be estimated, we get that ϵ and η are collinear. We thus calibrate ϵ consistently with the literature and estimate the extent to which the model departs from the Dixit-Stiglitz constant elasticity by allowing data to choose the value of η.

Considering the shape of the prior distributions, following standard practice, a beta distribution is adopted for parameters theoretically defined in a $[0-1]$ range, whereas a normal distribution is assumed for priors on parameters theoretically defined over the $\mathbb{R}$ range. As for the structural shocks, the reference distribution is the inverted gamma which is defined over the $\mathbb{R}^+$ range.

The prior mean for the Calvo parameter θ is set at 0.5 (implying that the average duration of a price is two quarters), with a standard deviation of 0.1. This relatively weak prior is based on Fabiani et al. 2010. For the sensitivity of firm demand elasticity to market share (the Kimball aggregator) η, we assume a very uniformative prior centered on zero with a standard error of 5. In other words, our prior is consistent with the hypothesis of a standard Dixit-Stiglitz constant demand elasticity and we let the estimates determine whether the data favor a Kimball aggregator characterized by a variable demand elasticity. The prior for the degree of backward indexation is assumed to be centered on 0.5 with a standard error of 0.1.

The parameters describing monetary policy are based on a standard Taylor rule: the prior mean of the Taylor coefficient on inflation ϕ_π and real activity ϕ_y is set at 1.5 and 0.5, with a standard deviation of 0.2 and 0.1, respectively, so as to guarantee a unique solution path when solving the model. The autoregressive coefficient ρ_r, capturing interest rate smoothness, has a diffuse prior mean of 0.5 with a prior standard error of 0.2.

The priors on the stochastic processes are harmonized and weakly informative, reflecting the very imprecise opinion about the dimensionality and the persistence of shocks (see table 2). The standard errors of the innovations have a prior mean of 0.01 with two degrees of freedom. All shocks are assumed to be serially correlated with autoregressive coefficient having a prior mean of 0.5 and a prior standard deviation of 0.2.

The measurement equations that link data to the corresponding model variables are described in the appendix.

7. Results

Tables 1 and 2 show, together with the prior distribution, the posterior mean and the 5th and 95th percentile of the posterior distribution of the parameters obtained through the Metropolis-Hastings

Table 1. Prior and Posterior Distribution of Structural Parameters

	Prior Distribution		Posterior Distribution 1981:Q2–1998:Q4	Posterior Distribution 1999:Q1–2012:Q2
	Distr.	**Mean (St. Dev.)**	**Mean (5%; 95%)**	**Mean (5%; 95%)**
θ Price Stickiness	$\mathcal{B}$	0.5 (0.1)	0.42 (0.26; 0.55)	0.66 (0.59; 0.72)
τ_p Degree of Backward Indexation	$\mathcal{B}$	0.5 (0.1)	0.45 (0.29; 0.61)	0.22 (0.12; 0.32)
η Kimball Aggregator	$\mathcal{N}$	0.0 (5.0)	0.85 (0.66; 0.95)	−2.00 (−2.64; −1.34)
ρ_r Monetary Policy Inertia	$\mathcal{B}$	0.5 (0.2)	0.18 (0.06; 0.30)	0.83 (0.79; 0.88)
ϕ_π Taylor Coefficient on Inflation	$\mathcal{N}$	1.5 (0.2)	1.82 (1.55; 2.13)	1.74 (1.46; 2.02)
ϕ_Y Taylor Coefficient on Real Activity	$\mathcal{N}$	0.5 (0.1)	0.03 (−0.03; 0.11)	0.60 (0.44; 0.75)

Notes: The posterior distribution is obtained using the Metropolis-Hastings algorithm.

Table 2. Prior and Posterior Distribution of Shock Processes

	Prior Distribution		**Posterior Distribution 1981:Q2–1998:Q4**	**Posterior Distribution 1999:Q1–2012:Q2**
	Distr.	**Mean (St. Dev.)**	**Mean (5%; 95%)**	**Mean (5%; 95%)**
Autoregressive Parameters				
ρ_μ Monetary Policy Shock	$\mathcal{B}$	0.50 (0.20)	0.06 (0.01; 0.10)	0.75 (0.70; 0.81)
ρ_ς Intertemporal Shock	$\mathcal{B}$	0.50 (0.20)	0.90 (0.84; 0.98)	0.53 (0.39; 0.66)
ρ_χ Intratemporal Shock	$\mathcal{B}$	050 (0.20)	0.97 (0.95; 0.99)	0.53 (0.42; 0.65)
ρ_A Technology Shock	$\mathcal{B}$	0.50 (0.20)	0.99 (0.98; 0.99)	0.95 (0.91; 0.99)
Standard Errors of Innovations				
σ_μ Monetary Policy Shock	$\mathcal{IG}$	0.01 (2)*	0.003 (0.002; 0.004)	0.004 (0.002; 0.005)
σ_ς Intertemporal Shock	$\mathcal{IG}$	0.01 (2)*	0.016 (0.005; 0.038)	0.044 (0.035; 0.053)
σ_χ Intratemporal Shock	$\mathcal{IG}$	0.01 (2)*	0.028 (0.024; 0.032)	0.029 (0.024; 0.034)
σ_A Technology Shock	$\mathcal{IG}$	0.01 (2)*	0.015 (0.013; 0.017)	0.003 (0.002; 0.004)

Notes: The posterior distribution is obtained using the Metropolis-Hastings algorithm. *For the inverted gamma distributions, degrees of freedom are indicated.

sampling algorithm, based on three chains of 1,000,000 draws.[16] Acceptance rates over the three chains are [0.236, 0.234, 0.228] for the first sample and [0.255, 0.254, 0.254] for the second one, close to the optimal acceptance rate of 0.234 (see Roberts, Gelman, and Gilks 1997). Markov chain Monte Carlo convergence diagnostics is discussed in the appendix.

The following conclusions can be drawn. Our estimates show that in the more recent years, the degree of intrinsic persistence (λ_1) has decreased, from 0.45 to 0.18, suggesting that the observed reduced-form inertia of inflation in recent years cannot be attributed to intrinsic inflation persistence but rather to an increase in extrinsic persistence. In particular, we document a vanishing tradeoff between inflation and economic activity. Indeed, the slope of the Phillips curve (λ_3) was 0.74 in the pre-1999 period and has reduced to 0.05 in the post-1999 period, which is in line with the estimates reported in Massidda and Mattana (2010). According to our estimates, such a flattening has been driven by increased strategic complementarity in price setting, on top of lower steady inflation and a longer average duration of prices, from 1.7 to 2.9 quarters.

Whereas data in the pre-1999 period favor the hypothesis of a constant demand elasticity, our estimates for the post-1999 period signal a much less convex demand curve compared with the Dixit-Stiglitz case.[17] When $\eta < 0$, the elasticity of demand faced by the firm depends inversely on its relative market share, hence the desired markup over marginal cost is decreasing in the firm's relative price. This flattens the Phillips curve, as for any given rise in unit labor cost, the firm will temper its price increase because of the endogenous drop in its desired markup. Indeed, for any given price increase, the firm will face a more elastic demand curve than for firms whose relative price declines as a result of prices remaining

[16]Note that in both of the sub-periods the estimated posterior means of the parameters are consistent with the condition $\beta\theta\overline{\Pi}^{(1+\eta)\epsilon\left(1-\tau_p\right)} < 1$. This condition is needed to ensure that in the deterministic steady state the infinite sums in the optimal pricing equation of the firms converge; see Ascari and Ropele (2009) for a similar condition in a setting with CES demand.

[17]The larger the η in absolute value, the more concave will be the demand curve.

fixed. Symmetrically, during recessions the firm will temper its price decrease because of the endogenous increase in its desired markup. Indeed, firms are more reluctant to reduce their price, as they would face a less elastic demand curve than those competitors whose relative price increases as a result of price fixity.

In other words, Basu (2005), Dotsey and King (2005), and Klenow and Willis (2006) show that a price elasticity of demand that is increasing in the firm's relative price leads to a smoothed version of a "kink" in the demand curve facing a given firm because it implies that consumers flee from individual items with high relative prices, but do not flock to inexpensive ones, thus creating "rigidity" in the relative price a firm wants. Hence, the higher sensitivity of the demand elasticity to the firm's relative price in the post-1999 period has weakened the relationship between economic activity and price dynamics in Italy and can account for the inertial adjustment of inflation. This change in real rigidities might be due to the increase in competitive pressure documented in Brandolini and Bugamelli (2009), as a consequence of the ICT revolution, globalization, and the process of European integration.[18] However, our model does not allow to capture the primitive sources driving this structural change, as it is not designed to disentangle the role of a change in preferences from that of a change in competition.

We have calibrated steady-state inflation to match the observed decline in the average annual sample producer price inflation, from 4.9 percent in the first sample to 2.4 percent in the second one. Whereas in a Dixit-Stiglitz world such a reduction would result in a steeper Phillips curve, when the elasticity of substitution between a given variety and others is increasing in the firm's good's relative price, the slope of the curve flattens when trend inflation falls. Our finding that the average duration of prices has increased by almost one quarter is consistent with the evidence documented using micro data that inflation correlates positively with the frequency of price adjustments: e.g., see Nakamura and Steinsson (2008) for results obtained using U.S. data, and Wulfsberg (2009) for an investigation carried out with Norwegian data. Also, our result is consistent

[18]See Sbordone (2010) for an extensive theoretical treatise of the effect of increased market competition on the degree of strategic complementarities in price setting and the slope of the Phillips curve in a framework similar to ours.

with the idea suggested by Ball, Mankiw, and Romer (1988) that the flattening of the Phillips curve at low levels of inflation might reflect the fact that there are costs associated with adjusting nominal prices that lead firms to change prices less frequently when inflation is lower. Cross-country evidence documented by Klenow and Malin (2010) confirms that firms do change prices less frequently when inflation is lower.

It is worth noting that another stark difference between the two sub-samples is the first-order autocorrelation of the monetary policy shock: in the pre-1999 period it was very small (0.06), so that the shock was close to a white noise; in the post-1999 period, after the start of the EMU, it increased sharply to 0.75. This evidence should be interpreted with caution: as mentioned above, the Taylor rule after 1999 cannot be interpreted, as usual, as the policy reaction function of the central bank, since monetary policy was conducted by the ECB at the euro-area level. Hence, the high level of the shock's persistence can capture a systematic difference in economic conditions between Italy and the average of the euro area.

8. Conclusions and Future Research

Debate over the Phillips curve has gained momentum since the financial crisis began in 2007. Indeed a puzzle has emerged, as inflation in advanced countries has not fallen as much as a traditional Phillips curve and past experiences would predict, given the severity and the duration of the recession. In this paper we focus on Italy and investigate the changes that occurred in the Italian Phillips curve.

According to our estimates, after 1999 the degree of "intrinsic persistence" in Italian inflation—i.e., the dependence of inflation on its own past—has diminished. In other words, in the more recent years, the degree of backwardness in price setting needed to account for the observed inflation persistence, while statistically significant, is not quantitatively important.

The slow response of inflation to economic activity observed in Italy in recent years may then be accounted for by the flattening of the Phillips curve. The latter is mainly due to the increase in strategic complementarities in price setting, on top of lower trend inflation and higher average duration of prices. The story that emerges from our estimates is as follows.

Whereas in the pre-1999 period the price elasticity of demand was almost constant, after 1999 the elasticity of substitution between a given variety and others is increasing in the firm's good's relative price, leading to strategic complementarities in price setting and to a flatter Phillips curve. Indeed, in a boom the firm will temper its price increase relative to the pre-1999 period because this will result in a more elastic demand curve than for those firms whose relative price declines as a result of price fixity. During recessions firms are more reluctant to cut their price relative to the past, as they would face a less elastic demand curve than their competitors whose relative price increases as a result of price rigidity.

In other words, as Basu (2005), Dotsey and King (2005), and Klenow and Willis (2006) show, a price elasticity of demand that is increasing with the firm's relative price generates a smoothed version of a "kink" in the demand curve facing a given firm. Indeed, it implies that consumers flee from individual items with high relative prices, but do not flock to inexpensive ones, creating "rigidity" in the relative price a firm wants. Hence, the higher sensitivity of the demand elasticity to the firm's relative price in the post-1999 period has weakened the relationship between economic activity and price dynamics in Italy and explains the slow adjustment of inflation during a severe and long-lasting recession.

A flatter Phillips curve involves a higher sacrifice ratio than otherwise, i.e., a longer spell of GDP below its natural level for every desired reduction in inflation. However, it also implies that an overheated economy will tend to induce a milder rise in inflation and, vice versa, reduces the risk of deflation in the face of severe downturns.

We see as fruitful directions for future research an investigation of the deep forces behind the increase in strategic complementarities we found in the estimation. Moreover, a cross-country analysis could shed light on the determinants underlying the differences between Italian and euro-area inflation dynamics.

Appendix

Phillips-Curve Coefficients

The generalized Phillips curve under trend inflation, strategic complementarities, and backward indexation can be described by the following system of equations:

$$
\begin{aligned}
\pi_t = {} & \frac{\tau_p\left(1+kDD\right)}{1+kDD+\widetilde{\beta}\tau_p}\pi_{t-1}+\frac{\widetilde{\beta}}{1+kDD+\widetilde{\beta}\tau_p}\mathbb{E}_t\left(\pi_{t+1}\right) \\
& +\frac{k}{1+kDD+\widetilde{\beta}\tau_p}\left(\widetilde{w_t^r}-\widetilde{mpn}_t\right)+\frac{\omega_1}{1+kDD+\widetilde{\beta}\tau_p}\mathbb{E}_t\widehat{\phi}_{t+1} \\
& +\frac{\omega_2}{1+kDD+\widetilde{\beta}\tau_p}\mathbb{E}_t\widehat{\varphi}_{t+1} \\
\widehat{\phi}_t = {} & \left[1-\beta\theta\overline{\Pi}^{(1+\eta)\epsilon(1-\tau_p)}\right]\left\{\left(\widetilde{w_t^r}-\widetilde{mpn}_t\right)+\left[\left(1+\eta\right)\epsilon BB-DD\right]\Delta_t\right\} \\
& +\beta\theta\overline{\Pi}^{(1+\eta)\epsilon(1-\tau_p)}\mathbb{E}_t\left[\widehat{\phi}_{t+1}+\left(1+\eta\right)\epsilon\Delta_{t+1}\right] \\
\widehat{\varphi}_t = {} & \beta\theta\overline{\Pi}^{-(1-\tau_p)}\mathbb{E}_t\left(\widehat{\varphi}_{t+1}-\Delta_{t+1}\right).
\end{aligned}
\tag{17}
$$

The coefficients $\widetilde{\beta}$, k, ω_1, and ω_2 are the following convolutions of deep parameters:

$$
\widetilde{\beta}\equiv\frac{\beta\theta}{CC}\left\{\begin{array}{c}\overline{\Pi}^{(1+\eta)\epsilon(1-\tau_p)}\left(1+\eta\right)\epsilon+\overline{\Pi}^{[(1+\eta)\epsilon-1](1-\tau_p)} \\ \times\left[\eta_{\varphi'}\left(\left(1+\eta\right)\epsilon-1\right)+AA\left(1-\eta_P\right)\right]-\eta_{\varphi}\overline{\Pi}^{-(1-\tau_p)}\end{array}\right\}
\tag{18}
$$

$$
k\equiv\frac{\overline{\widetilde{P}}'^{(1+\eta)\epsilon}\,\overline{\psi}^R}{\overline{\phi}}\frac{1}{CC}
\tag{19}
$$

$$
\omega_1=\frac{\beta\theta}{CC}\overline{\Pi}^{[(1+\eta)\epsilon-1](1-\tau_p)}\left\{\overline{\Pi}^{(1-\tau_p)}-1\right\}
\tag{20}
$$

$$
\omega_2=\frac{\beta\theta}{CC}\eta_{\varphi}\overline{\Pi}^{[(1+\eta)\epsilon-1](1-\tau_p)}\left\{\overline{\Pi}^{-(1+\eta)\epsilon(1-\tau_p)}-1\right\},
\tag{21}
$$

where we have defined

$$AA \equiv \frac{\theta \left\{ \left[(1-\theta) \tilde{\overline{P}}^{*1-(1+\eta)\epsilon} + \theta \left(\Pi^{\tau_p - 1} \right)^{1-(1+\eta)\epsilon} \right]^{\frac{1}{1-(1+\eta)\epsilon} - 1} \times \left(\Pi^{\tau_p - 1} \right)^{1-(1+\eta)\epsilon} + \eta \Pi^{\tau_p - 1} \right\}}{(1-\theta) \left\{ \left[(1-\theta) \tilde{\overline{P}}^{*1-(1+\eta)\epsilon} + \theta \left(\Pi^{\tau_p - 1} \right)^{1-(1+\eta)\epsilon} \right]^{\frac{1}{1-(1+\eta)\epsilon} - 1} \times \tilde{\overline{P}}^{*1-(1+\eta)\epsilon} + \eta \tilde{\overline{P}}^{*} \right\}} \tag{22}$$

$$BB \equiv \begin{aligned} &(1-\theta) \left[(1-\theta) \tilde{\overline{P}}^{*1-(1+\eta)\epsilon} + \theta \left(\Pi^{[(\tau_p - 1)(1-(1+\eta)\epsilon)]} \right) \right]^{-1} \\ &\times \tilde{\overline{P}}^{*[1-(1+\eta)\epsilon]} AA - \theta \left[(1-\theta) \tilde{\overline{P}}^{*[1-(1+\eta)\epsilon]} \right. \\ &\left. + \theta \left(\Pi^{[(\tau_p - 1)(1-(1+\eta)\epsilon)]} \right) \right]^{-1} \theta \left(\Pi^{[(\tau_p - 1)(1-(1+\eta)\epsilon)]} \right) \end{aligned} \tag{23}$$

$$DD \equiv \frac{\epsilon \alpha}{1-\alpha} \left[\frac{\left(\frac{\tilde{\overline{P}}}{\tilde{\overline{P}}'} \right)^{-(1+\eta)\epsilon}}{\frac{1}{1+\eta} \left(\frac{\tilde{\overline{P}}}{\tilde{\overline{P}}'} \right)^{-(1+\eta)\epsilon} + \eta} \right] (AA - BB). \tag{24}$$

Also, we have denoted with $\tilde{\overline{P}}^{*} \equiv \frac{P}{P}$ the relative price of the optimizing firm (which is different from 1 as long as the steady-state trend inflation is positive and $\tau_p < 1$) and with $\tilde{\overline{P}}' = \frac{P'}{P}$ the steady-state ratio between $P_t' = \left[\int_0^1 P_t(i)^{1-(1+\eta)\epsilon} di \right]^{\frac{1}{1-(1+\eta)\epsilon}}$ and P_t.

The Measurement Equation

We consider four time series: the log-differences of real GDP ($\Delta \log Y_t$) and of the real wage ($\Delta \log W_t^r$) obtained by deflating the earned income in manufacturing with the consumer price index, and the log-levels of producer price inflation $\log(P_t/P_{t-1})$ and of the short-term rate evaluated on a quarterly basis $\log(1+\frac{R_t}{400})$. Because the model is expressed in log-deviations around the deterministic growth path γ, the following measurement equation relates the set of observables (on the left side) to the corresponding model variables (on the right side):

$$\begin{bmatrix} \Delta \log Y_t \\ \Delta \log W_t^r \\ \log(P_t/P_{t-1}) \\ \log(1+\frac{R_t}{400}) \end{bmatrix} = \begin{bmatrix} \widetilde{y}_t - \widetilde{y}_{t-1} + \log \gamma \\ \widetilde{w}_t^r - \widetilde{w}_{t-1}^r + \log \gamma \\ \pi_t^p + \log \overline{\Pi} \\ r_t - \log \beta + \log \gamma + \log \overline{\Pi} \end{bmatrix},$$

where $\log \overline{\Pi}$ is the average sample quarterly inflation.

An Analysis of Local Identification Base on Iskrev (2010a, 2010b)

The last decade has seen a notable development in the specification and estimation of DSGE models with Bayesian full-information methods. Pure maximum likelihood is rarely used because the mapping of DSGE models' structural parameters to the coefficients of the reduced form is highly non-linear, weak identification is frequent, and Bayesian priors help to deal with likelihood functions presenting flat surfaces in the economically reasonable portion of the parameter space. However, as Canova and Sala (2009) stress, Bayesian methods, when improperly used, may conceal identification problems when they exist (on identification of Bayesian DSGE models, see also Kleibergen and Mavroeidis 2013 and Koop, Pesaran, and Smith 2013). The latter may arise for different reasons: a structural parameter might disappear from a log-linearized solution; two structural parameters might enter the objective function only proportionally, thus being separately unrecoverable; or the curvature of the objective function might be insufficient.

These problems are hard to tackle because, in most cases, the models at stake can only be solved numerically. It is often unfeasible to derive explicitly the relationship between the deep parameters and the statistical model used to estimate them and, thus, parameters' identification can only be assessed indirectly and with the use of numerical methods. In other words, it is generally impossible to establish what is called "global identification."

The latter can be defined as in Iskrev (2010b). Let $\xi \in \Xi$ be a k-dimensional vector of deep parameters, where ξ is a point in the parameter space $\Xi \subset R^k$. Let σ_T be the vector collecting the second moments of the data on which the estimation of ξ is based. Let X_T be the observed data. Then Iskrev (2010b) gives the following definition: *Suppose that the data X_T is generated by the model with parameter vector ξ_0. Then ξ_0 is globally identified by the second moments of X_T if and only if $\sigma_T(\xi) = \sigma_T(\xi_0) \Leftrightarrow \xi = \xi_0$ for any $\xi \in \Xi$. If the previous condition is true only for values in an open neighborhood of ξ_0, the identification of ξ_0 is only local.*

While it is often not possible to establish global identification, Iskrev (2010b) develops a rank condition for local identification that applies to identification with limited- as well as full-information methods. Local identification by itself does not guarantee that a model is globally identified. Nevertheless, as Iskrev (2010b) stresses, it is relevant to establish whether a model is locally identified for two main reasons: first, local identification is sufficient for the asymptotic properties of classical estimators to hold, and, second, parameters that are globally unidentifiable everywhere in the parameter space, either because they do not appear in the likelihood function at all or because they are indistinguishable from other parameters, are also locally unidentifiable. The rank condition developed by Iskrev (2010b) reads as follows: *Suppose that σ_T is a continuously differentiable function of ξ, and let ξ_0 be a regular point of the Jacobian matrix $J(T) \equiv \frac{\partial \sigma_T}{\partial \xi'}$. Then ξ_0 is locally identifiable if and only if $J(T)$ has a full column rank at ξ_0.*

In order to check formally whether estimation is possible or whether there are serious identification issues, we verify the necessary and sufficient conditions discussed by Iskrev (2010b) for the parameters declared in the prior definition at the prior mean. To do that, we make use of the routines developed by Ratto (2011).[19] In particular, we consider the chain rule: $J(T) = \underbrace{\frac{\partial \sigma_T}{\partial \tau'}}_{J_1(T)} \underbrace{\frac{\partial \tau}{\partial \xi'}}_{J_2}$, where J_2

[19]We refer to a computational tool developed by M. Ratto (Joint Research Centre, European Commission), with the contribution of Nikolai Iskrev (see Ratto 2011). The routines are a set of algorithms for identification analysis. The Dynare package, version 4, includes this tool for identification analysis of the DSGE models (Juillard 1996).

measures the effect of perturbations in ξ on the parameters characterizing the equilibrium of the model. Finding that matrix J_2 is rank deficient at ξ means that this particular point is unidentifiable in the model. Finding that J_2 has full rank but $J(T)$ does not means that ξ cannot be identified given the set of observed variables and the number of observations.

We get that both J_2 and $J_1(T)$ have full rank: all estimated parameters are locally identified at the prior mean.

We now turn to analyze how well identified are the identifiable parameters. Indeed, even if the likelihood is not completely flat, it can exhibit very low curvature with respect to some parameters, which are said to be, in this case, weakly identified. We evaluate the strength of identification by using the measures proposed by Iskrev (2010a) and the set of routines developed by Ratto (2011) for the Dynare package.

In particular, given the asymptotic information matrix $\mathcal{I}_T(\xi) = J_2'\Sigma(m_T)J_2$, where $\Sigma(m_T)$ is the covariance matrix of simulated moments, we compute two measures of the strength of identification. The first one is

$$s_i = \sqrt{\xi_i^2/(\mathcal{I}_T(\xi)^{-1})_{(i,i)}}. \tag{25}$$

This measure can be thought of as composed of two components: "sensitivity" and "correlation": weak identification can be attributable to the fact that changing ξ_i does not change significantly the likelihood, or that the effect on the likelihood of changing ξ_i can be offset by changing other parameters (multicollinearity). The sensitivity component is defined as

$$\triangle_i = \sqrt{\xi_i^2 \mathcal{I}_T(\xi)_{(i,i)}}. \tag{26}$$

The second one is obtained by using the prior standard deviation $\sigma(\xi_i)$ to normalize the identification strength:

$$s_i^{prior} = \sigma(\xi_i) / \sqrt{(\mathcal{I}_T(\xi)^{-1})_{(i,i)}}. \tag{27}$$

In this case the "sensitivity" component reads as follows:

$$\triangle_i^{prior} = \sigma(\xi_i) \sqrt{\mathcal{I}_T(\xi)_{(i,i)}}. \tag{28}$$

Figure 5. Identification Strength with Asymptotic Information Matrix (log-scale)

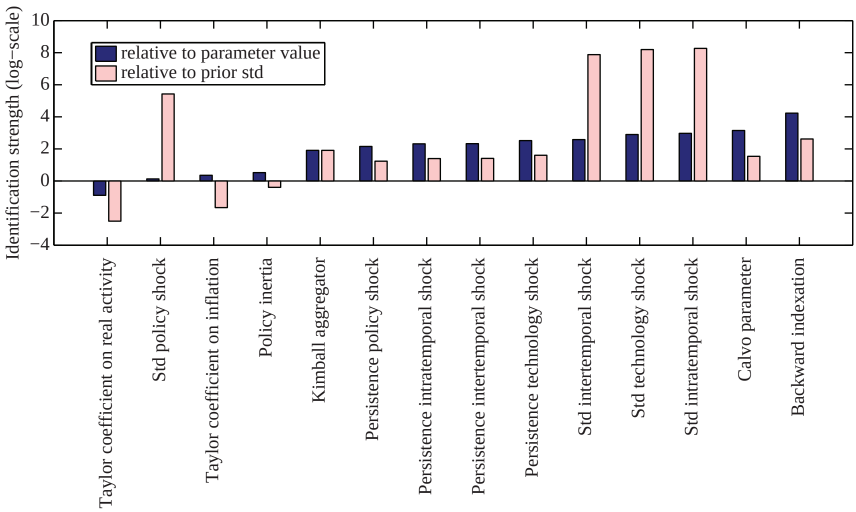
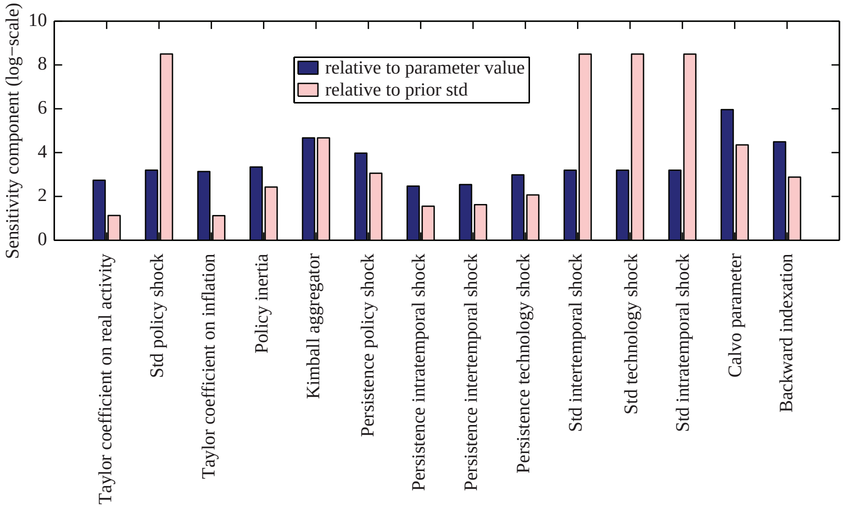


Figure 5 plots the strength of identification for all estimated parameters relative to both the parameter's value and its prior standard deviation (the model parameters on the x-axis are ranked in increasing order of strength of identification). Figure 6 shows the sensitivity component. We can conclude that all parameters are identified and have a non-negligible effect on the moments. However, identification is quite weak for the four parameters in the Taylor rule: ϕ_Y, σ_μ, ϕ_π, and ρ_r. This result is in line with an ample literature that has recently pointed out the weak identifiability of Taylor coefficients (see, for example, Cochrane 2011 and Qu and Tkachenko 2012). As expected, the comparison between figures 5 and 6 suggests that such weak identifiability depends on multicollinearity.

Markov Chain Monte Carlo Diagnostics

As specified in the main text, for each sample we run three chains of 1,000,000 Metropolis-Hastings simulations. If the results are sensible, they should be similar within any of the 1,000,000 iterations of Metropolis-Hastings simulations and close across chains. We refer to Brooks and Gelman (1998) to check for convergence.

Figure 6. Sensitivity Component with Asymptotic Information Matrix (log-scale)



More in particular, let ξ_{ij} be the i^{th} draw out of I, in the j^{th} sequence out of J. Let $\overline{\xi}_{\bullet j}$ be the mean of the j^{th} sequence and let $\overline{\xi}_{\bullet\bullet}$ be the mean across all available data. We define with $\widehat{B} = \frac{1}{J-1}\sum_{j=1}^{J}\left(\overline{\xi}_{\bullet j} - \overline{\xi}_{\bullet\bullet}\right)^2$ the estimate of the "between" variance of the mean σ^2/I, and with $B = \widehat{B}I$ an estimate of the variance. We denote with $\widehat{W} = \frac{1}{J}\sum_{j=1}^{J}\frac{1}{I}\sum_{i=1}^{I}\left(\overline{\xi}_{ij} - \overline{\xi}_{\bullet j}\right)^2$ and with $W = \frac{1}{J}\sum_{j=1}^{J}\frac{1}{I-1}\sum_{i=1}^{I}\left(\overline{\xi}_{ij} - \overline{\xi}_{\bullet j}\right)^2$ two estimates of "within" variance.

To have sensible results, one should have $lim_{I\to\infty}\widehat{B} \to 0$ and $lim_{I\to\infty}\widehat{W} \to$ constant. These can obviously be done for any moments, not just the variance.

Figures 7 and 8 report W (line with circles) and $(\widehat{W} + \widehat{B})$ (line with stars) of three measures of parameters moments: "m2," being a measure of the variance; "m3" based on third moments; and "interval," being constructed from the 80 percent confidence interval around the parameter mean. As was said before, to have reliable results, these should be relatively constant and should converge. Figures 9 and 10 show an aggregate measure based on the eingenvalues of the variance-covariance matrix. The horizontal axis represents

Figure 7. Convergence Diagnostic. Univariate Analysis. Pre-1999

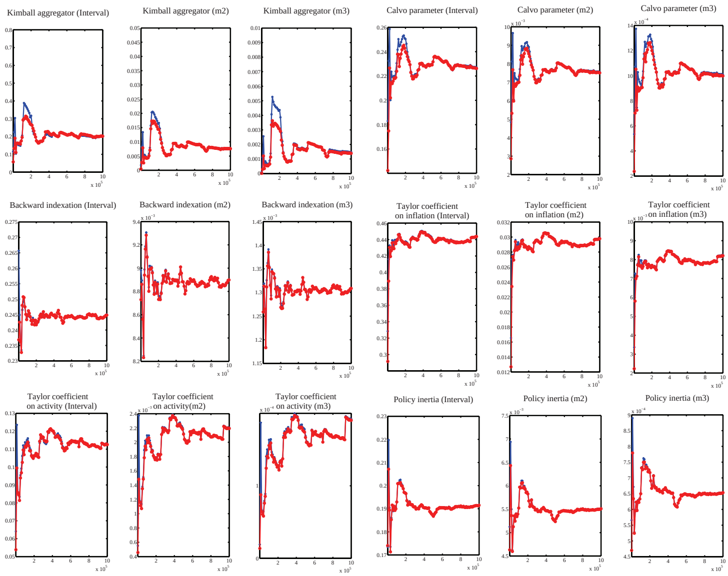


Figure 8. Convergence Diagnostic. Univariate Analysis. Post-1999

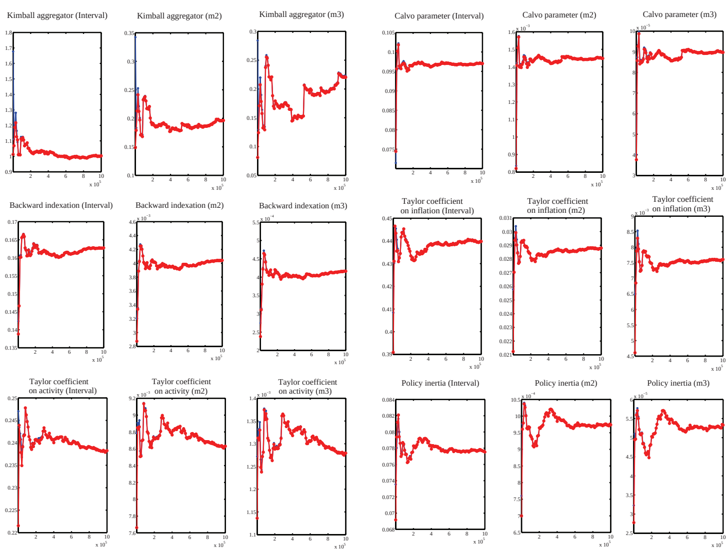


Figure 9. Convergence Diagnostic. Multivariate Analysis. Pre-1999

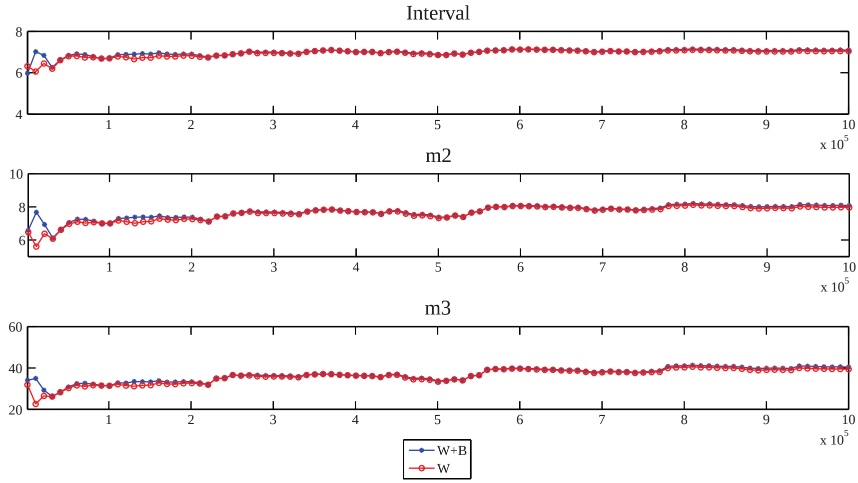
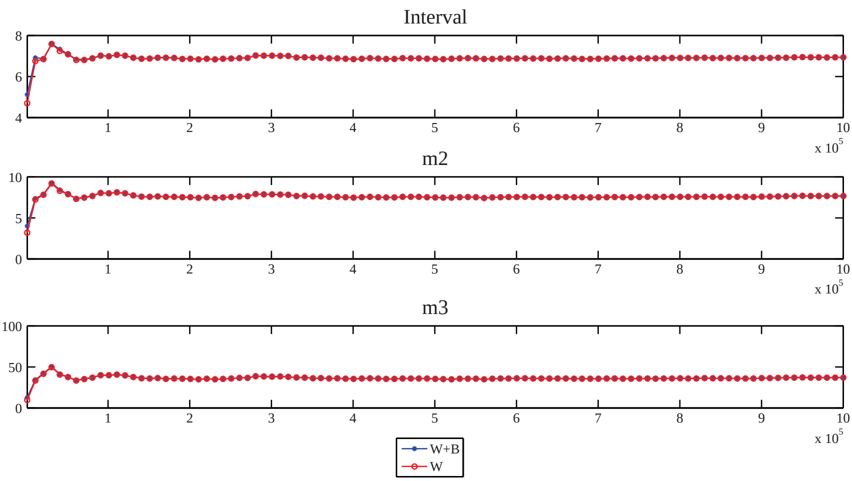


Figure 10. Convergence Diagnostic. Multivariate Analysis. Post-1999



the number of Metropolis-Hastings iterations, whereas the vertical axis represents the measure of the parameter moments.

Both univariate and multivariate analysis confirm that we obtain convergence and stability in all measures of the parameter moments.

References

Altissimo, F., M. Ehrmann, and F. Smets. 2006. "Inflation Persistence and Price-Setting Behavior in the Euro Area: A Summary of the IPN Evidence." ECB Occasional Paper No. 46.

Ascari, G. 2004. "Staggered Prices and Trend Inflation: Some Nuisances." *Review of Economic Dynamics* 7 (3): 642–67.

Ascari, G., and T. Ropele. 2007. "Optimal Monetary Policy Under Low Trend Inflation." *Journal of Monetary Economics* 54 (8): 2568–83.

———. 2009. "Inflation, Taylor Principle, and Indeterminacy." *Journal of Money, Credit and Banking* 41 (8): 1557–84.

Ascari, G., and A. Sbordone. 2013. "The Macroeconomics of Trend Inflation." Staff Report No. 628, Federal Reserve Bank of New York.

Ball, L. M. 2006. "Has Globalization Changed Inflation?" NBER Working Paper No. 12687.

Ball, L. M., G. Mankiw, and D. Romer. 1988. "The New Keynesian Economics and the Output-Inflation Tradeoff." *Brookings Papers on Economic Activity* 1: 1–82.

Ball, L. M., and S. Mazumder. 2011. "Inflation Dynamics and the Great Recession." *Brookings Papers on Economic Activity* 42 (1, Spring): 337–405.

Bardsen, G., E. S. Jansen, and R. Nymoen. 2004. "Econometric Evaluation of the New Keynesian Phillips Curve." *Oxford Bulletin of Economics and Statistics* 66 (s1): 671–85.

Basu, S. 2005. "Comment on 'Implications of State-Dependent Pricing for Dynamic Macroeconomic Models'." *Journal of Monetary Economics* 52 (1): 243–47.

Benigno, P., and J. D. López-Salido. 2006. "Inflation Persistence and Optimal Monetary Policy in the Euro Area." *Journal of Money, Credit and Banking* 38 (3): 587–614.

Bernanke, B. 2010. "The Economic Outlook and Monetary Policy." Speech delivered at the Federal Reserve Bank of Kansas City Economic Symposium, Jackson Hole, Wyoming, August 27.

Brandolini, A., and M. Bugamelli, eds. 2009. "Reports on Trends in the Italian Productive System." Occasional Paper No. 45, Bank of Italy.

Brooks, S. P., and A. Gelman. 1998. "General Methods for Monitoring Convergence of Iterative Simulations." *Journal of Computational and Graphical Statistics* 7 (4): 434–55.

Calvo, G. A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (3): 383–98.

Campbell, J. Y., and N. G. Mankiw. 1989. "Consumption, Income and Interest Rates: Re-interpreting the Time Series Evidence." In *NBER Macroeconomics Annual 1989*, ed. O. Blanchard and S. Fischer, 185–246. Cambridge, MA: MIT Press.

Canova, F., and L. Sala. 2009. "Back to Square One: Identification Issues in DSGE Models." *Journal of Monetary Economics* 56 (4): 431–49.

Cochrane, J. H. 2011. "Determinacy and Identification with Taylor Rules." *Journal of Political Economy* 119 (3): 565–615.

Cogley, T., and A. M. Sbordone. 2008. "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve." *American Economic Review* 98 (5): 2101–26.

Coibion, O., and Y. Gorodnichenko. 2013. "Is the Phillips Curve Alive and Well After All? Inflation Expectations and the Missing Disinflation." NBER Working Paper No. 19598.

Culver, S., and D. Papell. 1997. "Is There a Unit Root in the Inflation Rate? Evidence from Sequential Break and Panel Data Models." *Journal of Applied Econometrics* 12 (4): 435–44.

Daly, M., B. Hobijn, and B. Lucking. 2012. "Why Has Wage Growth Stayed Strong?" *Economic Letter* (Federal Reserve Bank of San Francisco) 2012-10 (April 2).

Dotsey, M., and R. King. 2005. "Implications of State-Dependent Pricing for Dynamic Macroeconomic Models." *Journal of Monetary Economics* 52 (1): 213–42.

Fabiani, S., A. Gattulli, G. Veronese, and R. Sabbatini. 2010. "Price Adjustment in Italy: Evidence from Micro Producer and Consumer Prices." *Managerial and Decision Economics* 31 (2–3): 93–104.

Fanelli, L. 2008. "Testing the New Keynesian Phillips Curve Through Vector Autoregressive Models: Results from the Euro Area." *Oxford Bulletin of Economics and Statistics* 70 (1): 53.

Fernandez-Villaverde, J., and J. F. Rubio-Ramirez. 2004. "Comparing Dynamic Equilibrium Models to Data: A Bayesian Approach." *Journal of Econometrics* 123 (1): 153–87.

Gaiotti, E. 2010. "Has Globalization Changed the Phillips Curve? Firm-Level Evidence on the Effect of Activity on Prices." *International Journal of Central Banking* 6 (1): 51–84.

Galí, J., and M. J. Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics* 44 (2): 195–222.

Giordano, C., and F. Zollino. 2013. "A Historical Reconstruction of Capital and Labour in Italy, 1861-2011." Mimeo, Bank of Italy.

Hall, R. E. 2011. "The Long Slump." *American Economic Review* 101 (2): 431–69.

———. 2013. "The Routes into and out of the Zero Lower Bound." Prepared for the Federal Reserve Bank of Kansas City's Annual Economic Symposium, "Global Dimensions of Unconventional Monetary Policy," Jackson Hole, Wyoming, August 23.

International Monetary Fund. 2013. "The Dog That Didn't Bark: Has Inflation Been Muzzled or Was It Just Sleeping?" In *World Economic Outlook* (April), chapter 3. Washington, DC: International Monetary Fund.

Iskrev, N. 2010a. "Evaluating the Strength of Identification in DSGE Models. An a Priori Approach." Mimeo.

———. 2010b. "Local Identification in DSGE Models." *Journal of Monetary Economics* 57 (2): 189–202.

Johansen, S. 1992. "Testing Weak Exogeneity and the Order of Cointegration in UK Money Demand Data." *Journal of Policy Modeling* 14 (3): 313–34.

Juillard, M. 1996. "Dynare: A Program for the Resolution and Simulation of Dynamic Models with Forward Variables through the Use of a Relaxation Algorithm." CEPREMAP Working Paper (Couverture Orange) No. 9602.

Kimball, M. S. 1995. "The Quantitative Analytics of the Basic Neomonetarist Model." *Journal of Money, Credit and Banking* 27 (4): 1241–77.

Kleibergen, F., and S. Mavroeidis. 2013. "Identification Issues in Limited Information Bayesian Analysis of Structural Macroeconomic Models." Mimeo.

Klenow, P. J., and B. A. Malin. 2010. "Microeconomic Evidence on Price-Setting." NBER Working Paper No. 15826.

Klenow P. J., and J. L. Willis. 2006. "Real Rigidities and Nominal Price Changes." Research Paper No. 06-03, Federal Reserve Bank of Kansas City.

Koop, G., M. H. Pesaran, and R. P. Smith. 2013. "On Identification of Bayesian DSGE Models." *Journal of Business and Economic Statistics* 31 (3): 300–314.

Lumsdaine, R. L., and D. H. Papell. 1997. "Multiple Trend Breaks and the Unit Root Hypothesis." *Review of Economics and Statistics* 79 (2): 212–18.

Massidda, C., and P. Mattana. 2010. "VAR Estimates of the New Keynesian Phillips Curve at Regional Level: The Case for Italy." Mimeo.

Mavroeidis, S., S. Plagborg-Møller, and J. H. Stock. 2013. "Empirical Evidence on Inflation Expectations in the New Keynesian Phillips Curve." Mimeo.

Molnár, K., and S. Santoro. 2014. "Optimal Monetary Policy When Agents Are Learning." *European Economic Review* 66: 39–62.

Nakamura, E., and J. Steinsson. 2008. "Five Facts about Prices: A Reevaluation of Menu Cost Models." *Quarterly Journal of Economics* 123 (4): 1415–64.

O'Reilly, G., and K. Whelan. 2005. "Has Euro-Area Inflation Persistence Changed over Time?" *Review of Economics and Statistics* 87 (4): 709–20.

Qu, Z., and D. Tkachenko. 2012. "Identification and Frequency Domain Quasi-maximum Likelihood Estimation of Linearized Dynamic Stochastic General Equilibrium Models." *Quantitative Economics* 3 (1): 95–132.

Ratto, M. 2011. "Algorithms for Identification Analysis under the DYNARE Environment: Final Version of Software." European Commission, Joint Research Centre.

Roberts, J. O., A. Gelman, and W. R. Gilks. 1997. "Weak Convergence and Optimal Scaling of Random Walk Metropolis Algorithms." *Annals of Applied Probability* 7 (1): 110–20.

Rumler, F. 2007. "Estimates of the Open Economy New Keynesian Phillips Curve for Euro Area Countries." *Open Economies Review* 18 (4): 427–51.

Sbordone, A. 2010. "Globalization and Inflation Dynamics. The Impact of Increased Competition." In *International Dimensions of Monetary Policy*, ed. J. Galí and M. Gertler. University of Chicago Press and NBER.

Schorfheide, F. 2000. "Loss Function Based Evaluation of DSGE Models." *Journal of Applied Econometrics* 15 (6): 645–70.

Shirota, T. 2007. "Phillips Correlation and Trend Inflation under the Kinked Demand Curve." Working Paper No. 7-E-5, Bank of Japan.

Smets, F., and R. Wouters. 2003. "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association* 1 (5): 1123–75.

———. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (3): 586–606.

Svensson, L. 2013. "The Possible Unemployment Cost of Average Inflation below a Credible Target." NBER Working Paper No. 19442.

Williams, J. C. 2006. "The Phillips Curve in an Era of Well-Anchored Inflation Expectations." Unpublished Working Paper, Federal Reserve Bank of San Francisco.

———. 2010. "Sailing into Headwinds: The Uncertain Outlook for the U.S. Economy." Presentation to Joint Meeting of the San Francisco and Salt Lake City Branch Boards of Directors, Salt Lake City, Utah, September 8.

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton, NJ: Princeton University Press.

Wulfsberg, F. 2009. "Price Adjustments and Inflation — Evidence from Norwegian Consumer Price Data 1975-2004." Working Paper No. 2009/11, Norges Bank.

Zivot, E., and D. W. K. Andrews. 1992. "Further Evidence on the Great Crash, the Oil-Price Shock, and the Unit-Root Hypothesis." *Journal of Business and Economic Statistics* 10 (3): 251–70.

Central Banks' Quasi-Fiscal Policies and Inflation*

Seok Gil Park
International Monetary Fund

Although central banks recently expanded their balance sheets by unconventional policy actions, little theory is available to explain how and when central banks' balance sheets affect inflation and impose restrictions on monetary policy. A DSGE model predicts that central banks' balance sheet shocks affect inflation through private agents' portfolio adjustments when fiscal authorities do not financially support central banks. In those cases, central banks cannot successfully unwind inflated balance sheets and stabilize inflation during the implementation of exit strategy. Therefore, fiscal authorities' backup is a pre-condition for effective monetary policy when central banks are engaged in quasi-fiscal policy roles.

JEL Codes: E31, E58, E63.

1. Introduction

Recently, central banks implemented unconventional operations by accumulating risky assets in an attempt to mitigate the financial turmoil that began in 2008 and the euro-zone fiscal crises. The operations altered the central banks' balance sheets in both size and substance, and the magnitude of these operations was significant.[1]

*The views expressed in this paper are those of the author and do not necessarily represent those of the IMF or IMF policy. An earlier version of this paper was circulated under the title "Quasi-Fiscal Policies of Independent Central Banks and Inflation." I am grateful to Eric Leeper, Joon Park, Abdelhak Senhadji, Lars Svensson, Todd Walker, Tack Yun, and participants at various conferences and seminars for their helpful comments. All remaining errors are mine. Author contact: International Monetary Fund, 700 19th Street, NW, Washington, DC, 20431. E-mail: spark@imf.org.

[1]For example, the Federal Reserve System's asset account was $894 billion at the end of 2007 but increased to $2.266 trillion at the end of 2008.

These operations can be referred to as a "quasi-fiscal policy" of central banks because they do not conform to traditional monetary policy, which is used to stabilize inflation by controlling the policy interest rate.[2] Instead of being innate to central banks, most of these activities could be implemented by fiscal authorities. In this paper, a quasi-fiscal policy is defined as any policy action that affects the central banks' balance sheets, with the exception of the traditional monetary policy mentioned above. For example, since credit-easing operations alter the composition of the central banks' asset accounts, they are considered quasi-fiscal policies.

Some have worried that the quasi-fiscal policies of the central bank may undermine its independence and ability to stabilize inflation (Sims 2003; Goodfriend 2011). In this regard, Goodfriend (2011) proposed accord principles between the central banks and fiscal authorities that will insulate the central banks from quasi-fiscal policy shocks (or central banks' balance sheet shocks). Also, an empirical study by Klüh and Stella (2008) showed that financially weak central banks were ineffective in stabilizing inflation. However, little economic theory is available to explain how and when the central banks' quasi-fiscal policy affects inflation and imposes restriction on monetary policy. The issue can be particularly crucial for central banks without sound fiscal support, such as the European Central Bank. This paper proposes a simple dynamic stochastic general equilibrium (DSGE) model in order to address the following questions: (i) Do quasi-fiscal policies and the central banks' balance sheets affect inflation? and (ii) Do the central banks' balance sheets have implications for policy interactions between the central banks and fiscal authorities?

The model predicts that the central banks' balance sheet shocks affect inflation through private agents' (households') portfolio adjustment when the fiscal authorities do not financially support central banks. That is, in that particular policy regime, the price level is determined by a ratio between the nominal and real value of the central bank's net liability. For example, suppose that a central

[2] Mackenzie and Stella (1996) defined a quasi-fiscal activity as "an operation or measure carried out by a central bank . . . with an effect that can, in principle, be duplicated by budgetary measures . . . and that has or may have an impact on the financial operations of the central bank" (p. 17).

bank with a negative capital suffers additional losses from long-term bond holdings while the central bank tries to increase the short-term interest rate in response to inflationary pressure. As the real value of holding the central bank's net liability falls below the equilibrium with the negative return shock, the private agent tries to decrease holdings of the central bank's liability (nominal money balance) and increase consumption. In the end, the general price level increases, and the central bank passively increases nominal money supply in order to satisfy real money balance demand. Paradoxically, the hike in the policy rate induces inflation in this case. In other words, the central bank is confined to a situation where it cannot play an active role in stabilizing inflation. Since fiscal support of the central bank's balance sheet precludes such type of equilibrium, therefore, the fiscal authority's backup is a pre-condition for effective monetary policy when the central bank is engaged in the other policy role such as maintaining financial stability.

Sargent and Wallace (1981), Leeper (1991), and Sims (1994) connected monetary and fiscal policy by showing that one policy may impose restrictions on the other policy, and that the two policies should interact in a coherent way in order to deliver a unique equilibrium. In this conventional approach to policy interaction, the budget constraints of the central banks and fiscal authorities are consolidated into a single equation. In other words, conventional models implicitly assume that the fiscal authorities acknowledge the central banks' liabilities and assets as their own liabilities and assets, and that the central banks' losses are automatically compensated by the fiscal authorities. Owing to these assumptions, in conventional models the budget constraint of the central banks does not impose restrictions on the equilibrium.

However, questions can be raised about this conventional assumption. Stella and Lönnberg (2008) surveyed 135 central banks and discovered that laws did not always guarantee the fiscal authorities' responsibility for the central banks' liabilities, and that the fiscal authorities are not always prompt in recapitalizing the central banks. In this regard, this paper relaxes the conventional assumption by elaborating on the institutional details which state that the central banks' flow budget constraint is separate from the fiscal authorities' flow budget constraint. In addition, this paper's public-sector model includes the fiscal authorities' transfer rule for recapitalizing the central banks, and this transfer rule is the key additional policy that interacts with other traditional policies (monetary and fiscal).

Furthermore, this paper departs from conventional models by assuming that the real values of the central banks' and fiscal authorities' liabilities have finite upper bounds, which are the expected present values of their future earnings. Owing to this assumption, the peculiar equilibria, where the fiscal authorities and central banks can run a Ponzi scheme on each other and the real value of the central banks' capital grows (or shrinks) infinitely, are excluded from this paper. By utilizing this assumption and the institutional details of the flow budget constraints, we show that the intertemporal equilibrium condition from the central banks' budget constraint (the central banks' net liability valuation formula) restricts equilibrium inflation in a certain policy regime.

In the above-mentioned policy regime, the transfer rule between the central banks and fiscal authorities is "active," while monetary and fiscal policies are "passive."[3] The active transfer rule means that the fiscal authorities do not stabilize the central banks' real capital and do not increase the fund transfer to the central banks when losses are incurred. As described in the previous example, monetary and fiscal policies are passively adjusted in order to satisfy the other equilibrium conditions, thus equilibrium inflation is uniquely determined by the central banks' net liability valuation formula in this regime. In this regard, this paper is an extension of the fiscal theory of the price level (FTPL) such as Leeper (1991). The model in this paper includes two intertemporal equilibrium conditions (from the public sector's separated flow budget constraints) and three policy instruments (monetary, fiscal, and transfer rule), whereas one intertemporal equilibrium condition (from the public sector's consolidated flow budget constraint) and two policy instruments (monetary and fiscal) exist in the conventional FTPL.

A few studies have been completed that shed light on the effects of concerns over the central banks' balance sheets. Jeanne and Svensson (2007) showed that if the central banks suffer losses when their capital falls below a fixed level, then the central banks' commitment

[3]Active and passive policies are defined by Leeper (1991). That is, an active policy is not constrained by the private agent's optimization (thus equilibrium conditions), states of the economy, and other policies.

to escape from the liquidity trap is more credible. Sims (2003) showed that the central banks' balance sheet concerns might undermine the central banks' abilities to prevent inflation. Berriel and Bhattarai (2009) showed that the optimal monetary policy is significantly different when the central bank's budget constraint is separate from the fiscal authorities' budget constraint. Specifically, as the central banks place higher effective weight on inflation in the loss function, the variation in inflation decreases.

One of the differences between this paper and previous literature on the central banks' balance sheets is that a new type of equilibrium exists even if the policy interest rate does not depend upon the status of the central banks' balance sheets. For example, in Jeanne and Svensson (2007) and Berriel and Bhattarai (2009), the central banks' loss function includes a deviation of the central banks' real capital. In these cases, the central banks' monetary policy behavior may be restricted by the balance sheet concerns. However, the monetary policy behavior in this paper follows a simple Taylor rule. In other words, the central bank, in this paper, will not generate seigniorage in response to its balance sheet concerns.

The remainder of this paper is organized as follows. In section 2, we build the model for the rational expectations general equilibrium in exact non-linear forms. In section 3, the equilibrium conditions are linearized around the deterministic steady state in order to derive analytic solutions. In addition, we explain the equilibrium in the active transfer rule regime in this section. The benchmark model is extended to include the exit strategy in section 4, and section 5 concludes the paper.

2. The Model

2.1 Private Agent's Optimization

This model is a closed-economy dynamic stochastic general equilibrium (DSGE) model with money in the utility function. Output is given by the exogenous endowment process $\{y_t\}_{t=0}^{\infty}$ for simplicity. The representative agent solves the following problem:

$$\max_{\{c_t, M_t, B_t^A\}_{t=0}^{\infty}} E_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ u(c_t) + v\left(\frac{M_t}{P_t}\right) \right\} \right], \quad 0 < \beta < 1, \tag{1}$$

such that

$$c_t + \frac{M_t}{P_t} + \frac{B_t^A}{P_t} \leq y_t - \tau_t + \frac{M_{t-1}}{P_t} + \frac{(1+i_{t-1})B_{t-1}^A}{P_t},$$

$$c_t, M_t \geq 0, \quad \forall t \geq 0,$$

$$M_{-1} + (1+i_{-1})B_{-1}^A > 0,$$

where $u(\cdot)$ is the utility function for consumption, $v(\cdot)$ is the utility function for the real money balance, c_t is the single consumption goods, τ_t is the lump-sum tax, M_t is the nominal money balance, the agent holds B_t^A units of the government's risk-free one-period nominal bonds, P_t is the price level, $E_t[\cdot]$ is the expectation based on the information available in period t, i_t is the risk-free net nominal interest rate, and the initial level of financial wealth $M_{-1} + (1+i_i)B_{-1}^A$ is given exogenously. The first-order condition yields the following Euler equations:

$$\frac{v'(m_t)}{u'(c_t)} + E_t\left[X_{t,t+1}\frac{P_t}{P_{t+1}}\right] = 1, \tag{2}$$

$$\frac{1}{R_t} = E_t\left[X_{t,t+1}\frac{P_t}{P_{t+1}}\right], \tag{3}$$

$$X_{t,t+1} \equiv \beta\frac{u'(c_{t+1})}{u'(c_t)}, R_t \equiv 1 + i_t,$$

where $u'(\cdot)$ and $v'(\cdot)$ refer to the first-order derivative of $u(\cdot)$ and $v(\cdot), m_t$ is the real money balance, $M_t/P_t, X_{t,t+1}$ is the real pricing kernel (or the discount factor) between period t and $t+1$, and R_t is the risk-free gross nominal interest rate. Equation (2) governs the money demand of the agent and equation (3) leads to the Fisher equation.

In order to ensure the existence of the agent's unique optimal choice, additional conditions should be assumed. Specifically, the agent cannot borrow a greater amount than the finite present value of her future income. This no-Ponzi-scheme restriction is expressed in the following condition:

$$w_t^A \equiv \frac{M_{t-1} + R_{t-1}B_{t-1}^A}{P_t} \geq -\sum_{T=t}^{\infty}[X_{t,T}(y_T - \tau_T)] > -\infty, \forall t, \tag{4}$$

where w_t^A is the agent's real financial wealth at period t and $X_{t,T} \equiv \prod_{s=t}^{T-1} X_{s,s+1}$. In the optimal path, the flow and intertemporal budget constraint are satisfied by equality and it can be shown that (1) and (4) lead to the following transversality condition:

$$\lim_{T\to\infty} E_t[X_{t,T} w_T^A] = 0, \forall t. \tag{5}$$

The market clearing conditions are imposed for the general equilibrium. Specifically, the goods market, the nominal money market, and the government bonds market should be cleared as follows:

$$c_t = y_t, \tag{6}$$

$$M_t^s = M_t, \tag{7}$$

$$B_t^s = B_t^A + B_t^C, \forall t, \tag{8}$$

where M_t^s is the nominal money supply, B_t^s is the government nominal bonds supply, and B_t^C is the central bank's demand for the government nominal bonds.[4] Then, after imposing market clearing conditions, the Euler equations turn into the following equilibrium conditions under the standard assumptions on preferences:

$$\frac{M_t^s}{P_t} = f^*\left(\frac{i_t}{1+i_t} u'(y_t)\right) \equiv f(y_t, i_t), \tag{9}$$

$$\frac{1}{R_t} = E_t\left[\beta \frac{u'(y_{t+1})}{u'(y_t)} \frac{P_t}{P_{t+1}}\right], \forall t, \tag{10}$$

where $f^*(\cdot)$ refers to the inverse function of $v'(\cdot)$. Equation (9) states that the supply of the real money balance should be equal to the agent's real money demand, and equation (10) is the Fisher equation. In order to completely define the rational expectations general equilibrium, the policy behavior of the fiscal authority and the central bank should be specified. Sections 2.2 and 2.3 will explain the public-sector model and the policy behavior.

[4]Determination of B_t^C will be explained in the next section.

2.2 Public-Sector Model

Goodfriend (2011) argued that the quasi-fiscal operations[5] of the central bank may undermine monetary policy's credibility and independence, thus an "accord" between the central bank and the fiscal authority is needed in order to ensure the central bank's ability to stabilize the economy. In his proposal, the accord principle is to minimize the central bank's exposure to balance sheet risks and to guarantee the central bank's credit to the private sector by the fiscal agent. Then the question is, what would happen in the general equilibrium model if such an accord does not exist? In order to tackle the issue, this section elaborates a public-sector model by incorporating the details of central banking.

The first aspect of institutional details is an isolation of the central bank's balance sheet from the fiscal authority. Owing to this factual aspect, the flow budget constraint of the consolidated government in conventional models is divided into two equations: one for the central bank and one for the fiscal authority. The second aspect consists of assumptions about the agent's expectations in regard to the two public institutions' liabilities. Similar to the no-Ponzi-scheme assumption in conventional models, the second-aspect assumptions turn the separated flow budget constraints of the two institutions into separated intertemporal equilibrium conditions (IECs). These separated intertemporal equilibrium conditions impose an additional restriction on the equilibrium, and the additional restriction is a main deviation from conventional models.

2.2.1 Separation of Flow Budget Constraint

The consolidated government's flow budget constraint in conventional models is as follows:

$$\underbrace{0}_{\Delta asset} = \underbrace{\frac{B_t^A - B_{t-1}^A}{P_t} + \frac{M_t - M_{t-1}}{P_t}}_{\Delta liability} + \underbrace{s_t - \frac{i_{t-1}B_{t-1}^A}{P_t}}_{\Delta capital}, \tag{11}$$

[5] Goodfriend (2011) defined "credit policy" as adjustments of asset portfolio composition of the central bank, such as "lending to particular borrowers with proceeds from the sale of treasuries." The credit policy, in his definition, can be rendered as quasi-fiscal policy, as it affects the central bank's balance sheet.

where the fiscal surplus s_t is the lump-sum tax τ_t less the fiscal authority expenditure in units of real goods.[6] The liability includes both the fiscal authority's debts issued to households and nominal money balance, since the balance sheets of two institutions have been consolidated in this case.

If the public-sector model reflects the fact that the central bank's balance sheet is isolated from the balance sheet of fiscal authority, then the consolidated constraint (11) should be divided into two constraints as follows:

$$\underbrace{\frac{B_t^C - B_{t-1}^C}{P_t}}_{\Delta asset} = \underbrace{\frac{M_t - M_{t-1}}{P_t}}_{\Delta liability} + \underbrace{\frac{i_{t-1}B_{t-1}^C}{P_t} + \kappa_t}_{\Delta capital}, \tag{12}$$

$$\underbrace{0}_{\Delta asset} = \underbrace{\frac{B_t - B_{t-1}}{P_t}}_{\Delta liability} + \underbrace{s_t - \kappa_t - \frac{i_{t-1}B_{t-1}}{P_t}}_{\Delta capital}, \tag{13}$$

where B_t refers to the fiscal authority's total debt sold to households and to the central bank ($B_t = B_t^C + B_t^A$), the central bank accumulates the fiscal authority's bonds (B_t^C) as an instrument for open-market operations, and κ_t refers to the transfer from the fiscal authority to the central bank in the real goods unit.[7] Note that the central bank's budget constraint (12) omits the central bank's various accounts such as risky loans to the financial sector, which are accrued by quasi-fiscal activities, for simplicity.

2.2.2 Separation of Intertemporal Equilibrium Condition

The central bank's separated budget constraint (12) is an accounting identity which does not necessarily affect equilibrium. However, an extra set of assumptions, which governs the private agent's expectations on the two public institutions' relationship, turns the identity into an equilibrium condition. The argument is similar to the conventional models' cases, such as Woodford (2001), where the

[6]The government spending is assumed to be zero for all time periods. No result relies on this assumption.

[7]Central banks generally submit their net profits to fiscal authorities. In this case, κ_t is a negative number.

consolidated government budget constraint (11) can be solved forward to derive the unified IEC (government debt valuation formula),

$$\frac{M_{t-1} + R_{t-1}B^A_{t-1}}{P_t} = \sum_{T=t}^{\infty} E_t\left[X_{t,T}\left(\frac{i_T}{1+i_t}f(y_T, i_T) + s_T\right)\right], \quad (14)$$

while the equilibrium conditions and the transversality condition (5) are substituted into the constraint.

Proposition 1 states that the unified IEC is separated into two IECs when the agent expects that the central bank and the fiscal authority have bounded real values for their liabilities.

PROPOSITION 1. *Suppose conditions (15) and (16) are true,* $|w^A_t| < \infty$,[8] *and* $P_t, X_{t,T} > 0$ *for all* t *and* $T > t$*:*

$$d^C_t \equiv \frac{M_{t-1} - R_{t-1}B^C_{t-1}}{P_t} \le \sum_{T=t}^{\infty} E_t\left[X_{t,T}\left(\frac{i_T}{1+i_T}f(y_T, i_T) + \kappa_T\right)\right] < \infty, \quad (15)$$

$$d^F_t \equiv \frac{R_{t-1}B^A_{t-1} + R_{t-1}B^C_{t-1}}{P_t} \le \sum_{T=t}^{\infty} E_t[X_{t,T}(s_T - \kappa_T)] < \infty. \quad (16)$$

Then the unified IEC (14) is separated into two IECs.

Proof. Note that $d^{C(F)}_t$ refers to the real net liability of the central bank (the fiscal authority) at period t and $w^A_t = d^C_t + d^F_t$. Intuitively, conditions (15) and (16) mean that the real values of the central bank and the fiscal authority liabilities cannot be greater than the expected present value of the future earnings. Appendix 1 shows that the following two equations are equivalent to conditions (15) and (16):

$$\lim_{T\to\infty} E_t[X_{t,T}d^C_T] = 0, \quad (17)$$

[8]Arguably, the real value of government liability (w^A_t) is bounded. One can imagine equilibria where the lump-sum-tax-to-output ratio is unbounded. In these equilibria, it may be possible that the government-liability-to-output ratio as well as the lump-sum-tax-to-output ratio are explosive, while the tax-to-debt ratio remains finite. Canzoneri, Cumby, and Diba's (2001) results showed the Ricardian equivalence under these equilibria. This paper excludes these bizarre equilibria by assumption.

$$\lim_{T\to\infty} E_t[X_{t,T} d_T^F] = 0, \ \ \forall t, \ \ T > t. \tag{18}$$

Then, the flow budget constraints (12) and (13) are turned into the following IECs by imposing equilibrium conditions (9) and (10), and conditions (17) and (18).

$$\frac{M_{t-1} - R_{t-1}B_{t-1}^C}{P_t} = \sum_{T=t}^{\infty} E_t\left[X_{t,T}\left(\frac{i_T}{1+i_T}f(y_T, i_T) + \kappa_T\right)\right], \tag{19}$$

$$\frac{R_{t-1}B_{t-1}^A + R_{t-1}B_{t-1}^C}{P_t} = \sum_{T=t}^{\infty} E_t[X_{t,T}(s_T - \kappa_T)]. \tag{20}$$

Note that equation (14) is a sum of equations (19) and (20).

I refer to the IEC (19) as "the central bank's net liability valuation formula" because equation (19) indicates that the real value of the central bank's net liability is equal to the expected present value of the seigniorage and the transfer earnings from (or payment to) the fiscal authority.[9] The IEC (20) states that the real value of the fiscal authority's total liability is supported by the current and future fiscal surplus less the transfer to the central bank. It should also be noted that equations (19) and (20) are not constraints, but are equilibrium conditions from the Euler equations, the optimal conditions, the agent's expectations on the policy institutions, and flow budget constraints.

Remark 1. *The crux of assumptions (15) and (16) is that the expected present value of the transfers between the two institutions is finite.*

In this model, the present values of the seigniorage and fiscal surplus converge to finite values. The convergence of the present value

[9]In order to ensure $P_t > 0$, it is further assumed that the expected present values of the seigniorage, the fiscal surplus, and the transfer are consistent with the positive price level. For example, in equation (19), the positive central bank capital ($M_{t-1} - R_{t-1}B_{t-1}^C < 0$) implies that the expected present value of future transfer from the central bank to the fiscal authority is greater than the seigniorage revenue.

of the seigniorage revenue can be shown by the agent's intertemporal budget constraint, which is inequality (21).[10]

$$\sum_{T=t}^{\infty} E_t \left[X_{t,T} \left(c_T + \frac{i_T}{1+i_T} \frac{M_T}{P_T} \right) \right] \leq w_t^A + \sum_{T=t}^{\infty} E_t \left[X_{t,T}(y_T - \tau_T) \right]. \tag{21}$$

The right side of inequality (21) is positive and bounded, which is implied by the agent's no-Ponzi-scheme assumption (4) and the assumption $|w_t^A| < \infty$. Since both consumption and the real balance holding are positive, then the present value of the seigniorage is finite in any equilibrium. The present value of the fiscal surplus should also be finite in the IEC (14). Since the terms other than the present value of transfer are all finite in (15) and (16), the validity of assumptions (15) and (16) hinges on the convergence of the expected present value of the transfers.

A sufficient condition for the convergence of the transfer in the deterministic case is presented in condition (22). Using the ratio test for the convergence of the infinite series, we get

$$\text{limsup} \left| X_{T,T+1} \frac{\kappa_{T+1}}{\kappa_T} \right| < 1, |\kappa_T| < \infty. \tag{22}$$

Condition (22) means that the transfer may grow faster than the real interest rate for only a finite number of time periods. If the transfer grows faster than the real rate for an infinite number of time periods, then the real values of the public institutions' liabilities will grow (or shrink) indefinitely by the flow budget constraints. In this case, the exploding transfer should ultimately be financed by the exploding B_C since the convergence of the seigniorage and surplus implies that the asymptotic growth rates of the seigniorage and surplus will fall below the real interest rate. The conventional models, without assumptions (15) and (16), have not excluded this peculiar scenario. In this perspective, the additional set of assumptions (15) and (16) is a lax requirement for the public-sector model because the exploding-liabilities scenario is hardly imaginable. Indeed, it is observed that restrictions (15) and (16) have been in effect, and

[10] The derivation of this formula follows proposition 2.1 in Woodford (2003).

that the restrictions become more plausible with the recent trend of the central banks' policy independence. These two rationales are elaborated as follows.

First, the value of the transfers between the governments and central banks (or banknote-issuing commercial banks) has been limited in the history of central banking. In the early stage of the central banks' evolution, they were bestowed a charter to issue monetary liability in return for financial favors to the governments. Although the early central banks provided financial services to the governments, the governments usually did not support the early central banks when they were in distress. This feature was revealed by the public's distrust of banknotes in the face of financial crises (Goodhart 1988, pp. 19–20). For example, the failure of John Law's Banque Royale in France (1720) and the suspension of gold convertibility in England (1797–1819) showed that governments have refused (or been unable) to support the values of the central banks' liabilities. If the governments' transfers to the central banks have infinite present values, then the government should have injected gold (or silver) into the central banks' vaults in order to ensure the convertibility of the banknotes. However, the exact opposite scenario has occurred in history. That is, the governments often suspended convertibility during times of fiscal need. Also, during some occasions, such as during the First World War in Germany, the central banks transferred funds to the governments on a large scale, but such operations came to an end with the occurrence of hyperinflation and regime changes.

Second, as more emphasis is placed on the central banks' policy independence, assumptions (15) and (16) (or equivalently, (17) and (18)) have become more plausible. That is, Sims (2003) claimed that a trend has occurred to prohibit the compulsory accumulation of the fiscal authority debts by the independent central bank, and that the transactions between the fiscal authority and the independent central bank should be mere by-products of monetary policy. The intuition on conditions (17) and (18) conforms to the above statements. Specifically, (17) and (18) imply that neither the central bank nor the fiscal authority can run a Ponzi scheme on the other entity. The Ponzi-scheme scenario is obviously unacceptable to the central banks which have policy independence where acquisitions of government debts only occur for monetary policy purposes. In other words, the policy-independent central bank is expected to reject extreme paths of transfer which violate condition (22) and the budgetary independence requirement. In sum, conditions (15) and (16) hold ubiquitously for the central banks and are a sensible assumption because the concept is well applicable to both the early central banks and the modern central banks which have policy independence.

2.3 Policy Behavior

In conventional literature, generally, monetary policy determines the path of the policy interest rate, while fiscal policy decides the path of the fiscal surplus $\{s_t\}$. A description of monetary and fiscal policy behavior is sufficient for determining a unique equilibrium price level in conventional literature because the two terms sufficiently characterize the policy behaviors in (14). However, in this paper, another policy rule must also be established in order to determine the equilibrium, as there is an additional unspecified policy variable $\{\kappa_t\}$. This section proposes a rule for the fiscal authority's transfer to the central bank $\{\kappa_t\}$.

2.3.1 Clarification on Quasi-Fiscal Policy

The term quasi-fiscal policy covers a wide range of policy behaviors. As it was already defined in the Introduction, quasi-fiscal policy refers to any action, except monetary policy, that affects the central bank's balance sheet. Additional clarifications can be made with respect to the following questions: (i) Which public institution decides quasi-fiscal policy? (ii) What are the policy instruments? and (iii) Why does this model focus on the transfer between the two institutions?

In regard to the authority in charge of quasi-fiscal policy, both the fiscal authority and the central bank may, in general, decide quasi-fiscal policy. For example, if the central bank decides to provide liquidity to the financial sector, the policy may be the central bank's decision. The transfer from the fiscal authority to the central bank is also quasi-fiscal policy, and if the fiscal authority decides not to transfer funds to the central bank, then the fiscal authority determines the quasi-fiscal policy in this case.

Policy instruments can also vary based on specific cases. In order to provide liquidity to the financial sector, the central bank can purchase risky assets from the financial sector. In this case, quasi-fiscal policy is implemented by adjusting the central bank's asset account. The sterilized foreign exchange rate intervention is another example in which the central bank's asset account (foreign reserve) is the policy instrument. When a quasi-fiscal activity is aimed at recapitalizing the central bank, the transfer rule from the fiscal authority to the central bank can be used as an instrument.

The benchmark model of this paper excludes all other quasi-fiscal policies and focuses only on the transfer from the fiscal authority to the central bank. This modeling choice is related to the notion of policies' activeness. Leeper (1991) stated that active policy is not constrained by the state of the economy. Specifically, in Leeper (1991), fiscal policy is active when the fiscal authority pays little attention to the level of the real value of government debt when it determines the fiscal policy instrument, the lump-sum tax. In other words, the level of government debt is one of the states of the economy in conventional models. In this paper, the state of the economy includes the level of government debt as well as the central bank's capital, which is obvious from the IEC (19) and (20). Then, the modeling choice is to determine which particular quasi-fiscal policy is the most appropriate instrument with which to target the central bank's capital. Targeting the central bank's capital means that the fiscal authority uses the quasi-fiscal policy instrument in order to maintain a certain level of the central bank's capital. Therefore, if the fiscal authority does not target the central bank's capital, the quasi-fiscal policy is active. One of the most direct ways to target the central bank's capital is to transfer funds from the fiscal authority to the central bank because the central banks do not generally impose direct taxes on the agent. Therefore, an appropriate way to model the central bank's capital targeting behavior is the transfer rule.

2.3.2 Policy Rules

In this section, linear policy rules are introduced in order to specify the policy behaviors. First, monetary policy follows the simple Taylor rule. That is, the central bank sets the risk-free gross interest rate (policy interest rate) in response to contemporary inflation as follows:

$$R_t = \alpha_0 + \alpha\pi_t + \theta_t, \tag{23}$$
$$\theta_t = \rho_\theta\theta_{t-1} + \varepsilon_{\theta t}, (0 \leq \rho_\theta < 1),$$

where α_t and α are policy parameters, θ_t refers to the monetary policy shock which follows the AR(1) process, and $\varepsilon_{\theta t}$ is white noise. Note that the central bank does not adjust the policy interest rate in response to its capital level. In other words, the model central bank does not try to target its capital by printing money.

Second, the fiscal authority determines the transfer to the central bank by following the next rule:

$$\kappa_t = \kappa_0 + \gamma_Q(\overline{cap} - b^C_{t-1} + m_{t-1}) + \xi_t, \tag{24}$$
$$\xi_t = \rho_\xi\xi_{t-1} + \varepsilon_{\xi t}, (0 \leq \rho_\xi < 1),$$

where κ_0 and γ_Q are policy parameters, ξ_t is the AR(1) random policy shock, $b^C_{t-1} - m_{t-1}(\equiv B^C_{t-1}/P_{t-1} - M_{t-1}/P_{t-1})$ is the real capital of the central bank, $\overline{cap}$ is the central bank's real capital target, and $\varepsilon_{\xi t}$ is white noise. The transfer rule (24) states that the transfer between the central bank and the fiscal authority may or may not be responsive to the level of the central bank's real capital. When the central bank's real capital falls below the target level ($\overline{cap}$), the fiscal authority's transfer to the central bank increases if the parameter γ_Q is strictly positive. If the parameter γ_Q is zero, then the fiscal authority does not adjust its transfer to the central bank in response to the level of the central bank's capital. The transfer shock ξ_t is the random part of the transfer. The following sections of this paper show that the central bank's earning shock may affect inflation when γ_Q is sufficiently small.

One may argue against the practical relevance of the transfer rule by assuming that κ_t always stabilizes the central bank's capital in practice. It is generally true that central banks remit their positive net profit to fiscal authorities, while maintaining a certain level of capital. However, in contradictory cases where the central bank has a negative net profit, the remittance from the fiscal authority to the central bank is not guaranteed. The asymmetry in the disposal of profits and losses is ubiquitous for the central banks around the world, including the Federal Reserve System of the United States (Stella and Lönnberg 2008). Even if the transfer (κ_t) becomes irresponsive to the central bank capital only temporarily, the transfer rule still may affect equilibrium. Chung, Davig, and Leeper (2007) showed that features of the other policy regime can be embedded into the equilibrium of the current regime through the agent's expectation in an environment where policy is switching between regimes.

Finally, the fiscal authority determines fiscal surplus s_t by the rule (25). Given this rule, the fiscal surplus may or may not be constrained by the level of the fiscal authority's debt.

$$s_t = \gamma_0 + \gamma_F b^A_{t-1} + \psi_t, \tag{25}$$
$$\psi_t = \rho_\psi \psi_{t-1} + \varepsilon_{\psi t}, (0 \leq \rho_\psi < 1),$$

where γ_0 and γ_F are the policy parameters, b^A_t is the real value of the fiscal authority's debt held by the agent (B^A_t / P_t), ψ_t is an AR(1) fiscal policy shock, and $\varepsilon_{\psi t}$ is white noise.

2.4 Equilibrium

The rational expectations general equilibrium is defined as the sequence of price $\{P_t\}$, the sequences of policy variables $\{R_t, s_t, \kappa_t\}$, and the sequences of allocations $\{c_t, M_t, M^s_t, B^A_t, B^A_t, B^C_t, B^s_t\}$. The sequences satisfy equilibrium conditions (9) and (10); the market clearing conditions (6), (7), and (8); the public-sector budget constraints (12) and (13); and the policy rules (23), (24), and (25), given the exogenous processes $\{y_t, \theta_t, \xi_t, \psi_t\}$. In addition, the optimal condition (5) and the assumptions (17) and (18) are satisfied in the equilibrium.

This paper focuses on the equilibrium in which the central bank's net liability valuation formula (19) uniquely determines the price level. Similar to Cochrane's (2001) characterization of the fiscal theory of the price level, the price level is determined by the ratio of the central bank's net liability to the present value of the central bank's future earnings in such equilibrium. The complete characterization of the policy regime in which such equilibrium is realized will be explored in section 3 within the context of a linearized system.

3. Linearized System

In this section, the equilibrium conditions are linearized around the deterministic steady state, while the equilibrium conditions are expressed in exact non-linear forms in section 2. Specifically, this section's analysis is restricted to the equilibria with the bounded inflation rate and real values of bonds (b_t^A and b_t^C).[11] In addition, this section assumes the log-utility function and a constant output for simplicity.

$$u(c_t) = \log c_t, v\left(\frac{M_t}{P_t}\right) = \chi \log \frac{M_t}{P_t}, y_t = y, \forall t, \tag{26}$$

where χ is a parameter for the marginal rate of substitution between consumption and the real money balance. In this simple case, the equilibrium conditions from the private agent's behavior, (9) and (10), become the next two equations.

$$\frac{M_t}{P_t} = \chi y \frac{R_t}{R_t - 1}, \tag{27}$$

$$\frac{1}{R_t} = \beta E_t\left[\frac{1}{\pi_{t+1}}\right], \tag{28}$$

where the inflation rate $\pi_{t+1} \equiv P_{t+1}/P_t$. Another notable simplification from the log-utility and constant output assumption is that the seigniorage and real pricing kernel are constant for each period.

$$\frac{i_t}{1+i_t} f(y_t, i_t) = \chi y, \tag{29}$$

$$X_{t,t+1} = \beta, \forall t. \tag{30}$$

3.1 Policy Interactions

The linear dynamic system is derived from the equilibrium conditions of the private agents' optimization ((27) and (28)), the policy

[11] If we restrict the analysis to the equilibria with the bounded inflation, then the real values of bonds should also be bounded owing to the assumptions of proposition 1.

rules ((23), (24), and (25)), and the public sector's flow budget constraints ((12) and (13)), after they have been linearized. In order to apply Sims's (2001) algorithm, the system is summarized in a matrix form as follows:

$$\Gamma_0 x_{t+1} = \Gamma_1 x_t + \Phi_0 z_{t+1} + \Phi_1 z_t + \Pi_{t+1}, \tag{31}$$

where the vector of the endogenous variables is $x_1 \equiv (d\pi_t, db_t^C, db_t^A)'$, the vector of the exogenous shocks is $z_t \equiv (\theta_t, \xi_t, \psi_t)'$, the forecast-error vector is $\Pi_{t+1} \equiv (\eta_{t+1}, 0, 0)', \eta_{t+1} \equiv \pi_{t+1} - E_t[\pi_{t+1}], \Gamma$ and Φ are 3×3 parameter matrices, and the "d" notation is used for the linear deviation from the deterministic steady state.

PROPOSITION 2. *Three regions of policy parameter space (regimes) deliver unique stationary solutions of the system (31).*

Proof. In order to uniquely determine the system's (31) solution, only one of the eigenvalues of the transition matrix $\Gamma_0^{-1}\Gamma_1$ should be greater than one in absolute value because only one endogenous forecast error (η_{t+1}) exists in the system.[12] The three eigenvalues are as follows:

$$\alpha\beta, \beta^{-1} - \gamma_Q, \beta^{-1} - \gamma_F.$$

That is, the existence and uniqueness of the solution depends upon the policy parameters (α, γ_Q, and γ_F) and the deep behavioral parameter (β). In addition, each policy parameter has one associated eigenvalue within the system. If an active policy is defined as the policy for which the associated eigenvalue is unstable, then it is obvious that only one of the three policies should be active in order for the system to have a unique solution. The three policy regimes that determine unique equilibria are as follows:

$$\begin{array}{llll} \text{AMP regime:} & |\alpha\beta| > 1, & |\beta^{-1} - \gamma_Q| < 1, & |\beta^{-1} - \gamma_F| < 1, \\ \text{ATR regime:} & |\alpha\beta| < 1, & |\beta^{-1} - \gamma_Q| > 1, & |\beta^{-1} - \gamma_F| < 1, \\ \text{AFP regime:} & |\alpha\beta| < 1, & |\beta^{-1} - \gamma_Q| < 1, & |\beta^{-1} - \gamma_F| > 1. \end{array}$$

[12]The detailed derivation of the solution is described in appendix 2.

The active monetary policy (AMP) and active fiscal policy (AFP) regimes are well-known policy regimes. In the AMP regime, the monetary policy actively sets the policy interest rate in order to stabilize inflation, while passive fiscal policy supports the real value of the fiscal authority's liability. In the AFP regime, the expected path of the fiscal surplus determines inflation, while the monetary policy passively accommodates the determined inflation path by adjusting the nominal money balance. A novel finding of this paper is the equilibrium in the active transfer rule (ATR) regime and the requirements for the passive transfer rule when other policies are active. In the ATR regime, the active transfer rule determines inflation, and other policies are passive in the same way as in the other regimes. When the transfer rule is passive, it tries to support the real value of the public-sector liability.

A brief intuition of this policy interaction can be found in the following equilibrium conditions:

$$E_t[d\pi_{t+1}] = \alpha\beta d\pi_t + \beta d\theta_t, \tag{32}$$

$$\frac{-(m - Rb^C)}{\pi^2} d\pi_t = \sum_{T=t}^{\infty} E_t[\beta^{T-t}(\chi y + d\kappa_T)], \tag{33}$$

$$\frac{-(Rb^C - Rb^A)}{\pi^2} d\pi_t = \sum_{T=t}^{\infty} E_t[\beta^{T-t}(ds_T - d\kappa_T)], \tag{34}$$

where (32) is the linearized Fisher equation after substituting the monetary policy rule and m, R, b^C, b^A, and π are the steady-state values. Equations (33) and (34) are simplifications of the IECs (19) and (20) using equations (29) and (30).[13]

First, if monetary policy is active ($|\alpha\beta| > 1$), the expectational difference equation (32) can be utilized to determine π_t. In this case, for the existence and uniqueness of the solution, the transfer $\{\kappa_T\}$ should support the real value of the central bank's liability (left side of the IEC (33)) by being endogenously determined through the IEC (33). Meanwhile, the fiscal surplus $\{s_T\}$ should be passively adjusted

[13]The IECs (33) and (34) are derived by linearizing the IECs (19) and (20) around the steady state by assuming that the economy was in the steady state at period $t - 1$.

in order to support the real value of the fiscal authority's liability in the IEC (34).

Second, active transfer rule ($|\beta^{-1} - \gamma_Q| > 1$) implies that the transfer $\{\kappa_T\}$ is not responsive to the state of the central bank's capital. Then, $\{\kappa_T\}$ can be regarded as an exogenous process in the IEC (33). Therefore, the IEC (33) imposes a restriction on inflation since all variables other than inflation are predetermined or exogenous. The passive monetary policy in equation (32) ($|\alpha\beta| < 1$) means that the expectational difference equation (32) does not restrict inflation π_t. Again, the passive fiscal policy supports the real value of the fiscal authority's liability so that the IEC (34) does not bind inflation.

Third, when the fiscal policy is active, the monetary policy and transfer rule should be passive. Specifically, equation (32) should not impose an additional restriction on inflation, and the transfer $\{\kappa_T\}$ should be passive in a way that it is endogenously determined by the IECs (33) and (34), simultaneously. Since the endogenous process $\{\kappa_T\}$ appears in both the IECs, the two IECs jointly determine inflation. In other words, the unified IEC (14) is the single equation to be imposed on the inflation process. Note that this equilibrium is the same as in the fiscal theory of the price level.

A notable feature of the policy interaction is that passive monetary policy does not need to raise the seigniorage revenue in order to cover the decreased transfer from the fiscal authority or the decreased fiscal authority surplus. The real seigniorage revenue is even a fixed number (χy) for all of the periods in this model. Even if the seigniorage is a function of the nominal interest rate under general circumstances, it is still the case that the nominal interest rate is not responsive to inflation when monetary policy is passive. Therefore, in this case, the present value of the seigniorage in the IEC (33) can be treated as a fixed number. In sum, it is a misleading statement that passive monetary policy raises the seigniorage in order to balance the intertemporal budgets. Instead, the passive central bank adjusts the nominal money balance in order to accommodate the real money market clearing condition (9) in accordance with the equilibrium price level, which is determined elsewhere.

3.2 Equilibrium in the Active Transfer Rule Regime

As discussed in proposition 2, if the transfer rule is active while the monetary and fiscal policies are passive, then a unique stationary equilibrium inflation path exists. The nature of this equilibrium is different from that of AMP and AFP regimes, as the transfer rule shock affects surprise inflation and the direction of the effect depends upon the steady-state value of the central bank's capital.[14] For a simple illustration, the following special case is considered:

$$\alpha, \gamma_Q, \rho_\theta, \rho_\xi, \rho_\psi = 0, |\beta^{-1} - \gamma_F| < 1. \tag{35}$$

The central bank pegs the policy interest rate ($\alpha = 0$), the fiscal authority's transfer to the central bank is not responsive to the level of the central bank's capital ($\gamma_Q = 0$), the policy shocks are independent and identically distributed (i.i.d.), and the fiscal authority sufficiently adjusts the lump-sum tax in response to the level of its own debt held by the agent. In this case, surprise inflation is a function of the shock in the transfer, $\varepsilon_{\xi t}$.

$$\eta_t = \frac{\pi^2}{Rb^C - m}\varepsilon_{\xi t}, \tag{36}$$

where R is the steady-state value of the gross interest rate, b^C is the steady-state real value of the central bank's holding of the fiscal authority bonds, m is the steady-state value of the real money balance, and $Rb^C - m$ is the steady-state value of the central bank's real capital. If the benchmark model is extended to include risky assets of the central bank, then the random return shocks from the asset will also affect surprise inflation as shown in section 4.

Inflation is the sum of the expected inflation and surprise inflation. Since the surprise inflation was solved in equation (36), inflation is determined as follows in the ATR regime:

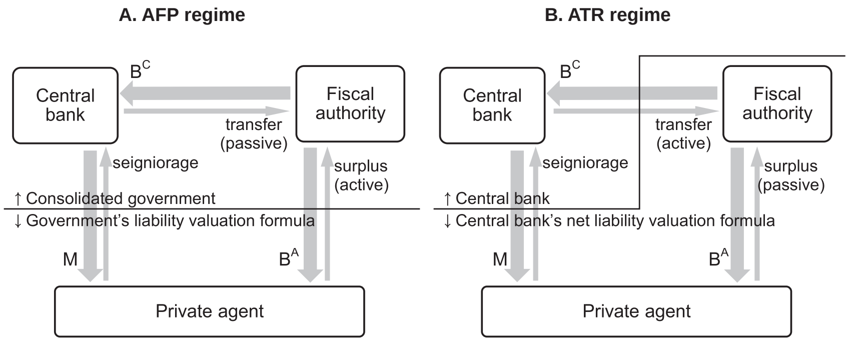
$$d\pi_t = \beta\varepsilon_{\theta t-1} + \frac{\pi^2}{Rb^C - m}\varepsilon_{\xi t}. \tag{37}$$

Note that $\beta\varepsilon_{\theta t-1}$ is the expected inflation $E_{t-1}[d\pi_t]$ in this case.[15] The solution in equation (37) implies that the tightening monetary

[14]Equilibria in AMP and AFP regimes are fundamentally the same as in conventional models, such as in Leeper (1991). Thus, those equilibria are not discussed in this paper.

[15]This point can be shown by setting $\alpha = 0$ in equation (32).

Figure 1. Analogy Diagram of Two Different Policy Regimes



policy shock (positive $\varepsilon_{\theta t-1}$) increases inflation in the next period via the expected inflation. The result is consistent with the simple fiscal theory of the price level (Leeper 1991) and the "unpleasant monetarist arithmetic" (Sargent and Wallace 1981).

The equilibrium inflation in the ATR regime is similar to that of the AFP regime, in the sense that the monetary policy shock ($\varepsilon_{\theta t}$) does not affect current inflation. Instead of the monetary policy shock, the other policy shocks that alter the value of public sector's liability affect inflation in these cases. The difference between the equilibria in those two policy regimes is the coverage of the public-sector liability value which binds equilibria. That is, while the valuation equation for the consolidated government's liability binds equilibrium inflation in the AFP regime, the central bank's net liability valuation equation determines equilibrium inflation in the ATR regime.

The analogy between the two regimes is helpful for understanding the economic intuition underlying the equilibrium inflation in both regimes. Figure 1 compares the two cases by illustrating financial portfolios of the three players of the economy (private agent, central bank, and fiscal authority) and flow of resources between the players in return for the assets. For example, the value of the private agent's government bonds holdings (B_t^A) is supported by the fiscal surplus flows (s_t). The seigniorage (χy) and transfer ($-\kappa_t$) support values of the nominal money balance (M_t) and the central bank's government bonds holdings (B_t^C), respectively. Note that the seigniorage is a fixed number in this model for simplicity, as shown in equation (29).

Woodford (2001) and Cochrane (2005) utilized an "asset pricing analogy" in order to explain economic intuition of the fiscal theory of the price level. That is, the private agent's holdings on the consolidated government's liability can be regarded as holdings on shares of the consolidated government. In Cochrane's (2005) term, the consolidated government's liability (M and B^A) is a "residual claim to government primary surplus" and seigniorage, "just as Microsoft stock is a residual claim to Microsoft's earnings." As a stock price is determined by the expected present value of its earnings, the price level[16] is determined by the expected present value of seigniorage and the primary surplus in the AFP regime. For example, the unexpected tax cut that is not compensated by future tax hikes makes the agent feel wealthier, as "the stock" price is higher than the equilibrium level. Therefore, the private agent tries to adjust his portfolio between consumption and the government's nominal liability, and inflation follows.

Figure 1's panel A shows that, technically, the private agent holds two different stocks (money and government bonds) from two distinct firms (central bank and fiscal authority). However, because the fiscal authority is committed to support the central bank's liability value with the transfer (passive transfer rule), the private agent is indifferent to the distinction between the two firms' stocks. Moreover, the price of the two stock prices are synchronized by a common price $1/P_t$. In the asset pricing analogy's term, the two firms are in effect merged. Therefore, the central bank and the fiscal authority are treated as a unified entity in the conventional fiscal theory of price level.

Panel B shows that such unification between the two entities is no longer valid in an ATR regime. As one firm (fiscal authority) does not support the value of the other firm's (central bank's) stock and the cash flow between the two firms (transfer) is exogenously given, the stock prices of two firms should be independently determined. However, in an ATR regime, the private agent understands that the earnings of a firm (the fiscal authority) are endogenously adjusted in

[16]The common price of M_t, B_t^A, and B_t^C in units of consumption goods is $1/P_t$.

response to the stock price (the price level) which is determined elsewhere.[17] Therefore, the valuation equation for the other firm (the central bank's net liability valuation formula) uniquely determines the common stock price.

Suppose that a negative transfer shock ($\xi_t < 0$) decreases the transfer from the fiscal authority to the central bank (κ_t) unexpectedly. Then, a portfolio adjustment will occur on the part of the private agent. However, the direction of the portfolio adjustment depends on the central bank's capital ($Rb^C - m$) at steady state. In the case of negative capital (positive net liability of central bank), the positive net liability value should be supported by the present value of seigniorage and the transfer from the fiscal authority. Owing to the shock, the real value of the net liability (left side of equation (19)) becomes greater than the equilibrium level (right side of equation (19)) if the price level remains the same as the level before the shock. The situation is similar to the tax cut example in an AFP regime, and the private agent feels wealthier. Therefore, as the private agent tries to consume more and hold less money, the negative transfer shock induces inflation in this case. At the equilibrium, the fiscal authority's real debt burden is alleviated and the implicit tax burden on the agent decreases.

Conversely, the negative transfer rule shock induces deflation when the steady-state capital of the central bank is positive. In order to intuitively describe this case, suppose that the private agent lends to the fiscal authority ($B^A < 0$) in a greater amount than the nominal money holdings ($-B^A - M > 0$) in an AFP case (panel A). Then, the private agent is not the (consolidated government's) liability holder but is the liability issuer. The value of liability to the fiscal authority should be supported by the lump-sum subsidy (from the fiscal authority to the private agent), not the lump-sum tax. A slight modification of the consolidated government's liability valuation formula (14) shows this situation as follows:

$$\frac{-R_{t-1}B^A_{t-1} - M_{t-1}}{P_t} = \sum_{T=t}^{\infty} E_t \left[X_{t,T} \left(s'_T - \frac{i_T}{1+i_T} f(y_T, i_T) \right) \right], \tag{38}$$

[17]This situation refers to passive fiscal policy behavior.

where s' refers to lump-sum subsidy to the private agent. That is, the consolidated government's capital is positive and the capital value is supported by the lump-sum subsidy less seigniorage. If the lump-sum subsidy unexpectedly increases and the general price level remains the same, the private agent finds that the liability value $((-B^A))$ falls below the equilibrium level (right side of (38)). Since the prices of B^A and M are synchronized, the private agent tries to consume less and hold more money, and deflation follows.

The argument for the positive central bank capital case is similar. The modification of the central bank's net liability valuation formula (19) shows that the central bank's positive capital value is equivalent to the transfer to the fiscal authority less seigniorage as in the following equation:

$$\frac{R_{t-1}B^C_{t-1} - M_{t-1}}{P_t} = \sum_{T=t}^{\infty} E_t \left[X_{t,T} \left(\kappa'_T - \frac{i_T}{1+i_T} f(y_T, i_T) \right) \right], \quad (39)$$

where κ' refers to transfer from the central bank to the fiscal authority. The negative transfer shock increases κ' and the private agent finds that the liability value (B^C) falls below the equilibrium level. The portfolio adjustment between the nominal money balance and consumption induces deflation in the end.

Two important features of the equilibrium should be noted. First, the model's economic mechanism for inflation does not rely on the central bank's money creation in response to the transfer to the government. In the first step of the adjustment procedure, the central bank fixed the nominal money balance, but inflation (deflation) is still induced by the transfer rule shock. A similar statement can be made for the fiscal theory of the price level. In the active fiscal policy regime, the tax shock does not require the creation of money in order to have an impact on the price level. Otherwise, the tax shock induces the agent's portfolio adjustment, and, thus, the price changes. Therefore, this model's application is never restricted to extreme situations, such as a large-scale transfer between two public institutions.

Second, the equilibrium in the ATR regime is observationally equivalent to the equilibria in the AMP and AFP regimes. Suppose that a transfer shock causes inflation in the ATR regime. Then, the nominal money balance must be increased passively in order to clear the money-market equilibrium condition (27) and the future fiscal surplus must be passively decreased in accordance with the price change by the fiscal policy rule (25). The required tax change in the present value can be shown by adding (19) to (20). This observational relationship between inflation, the nominal money balance, and the fiscal surplus is the same as in the other regimes, although the causal relationships are opposite. For instance, in the AMP regime, an expansion of the nominal money balance (a negative monetary policy shock) causes inflation and the fiscal surplus is passively decreased. In the AFP regime, the decrease in the fiscal surplus causes inflation and the nominal money balance is passively increased.

4. Application to Exit Strategy

In order to link the equilibria in the ATR regime to actual quasi-fiscal policies, this section extends the benchmark model to include longer-term government bonds and an exit strategy example. Exit strategy refers to plans to reverse unconventional quasi-fiscal operations, such as credit-easing operations, as economic recovery and inflation become imminent. Specifically, the Federal Reserve System will be required to "reduce excess reserve balances" of depository institutions or "neutralize their potential effects on broader measures of money and credit and thus, on aggregate demand and inflation" (Bernanke 2009). Roughly explained, the exit strategy is the plan to decrease the size of the central bank's balance sheet by selling the assets that have been acquired via unconventional operations.

This section analyzes the exit strategy's potential effects on inflation by extending the benchmark model to include the long-term bonds. Although the primary policy intent of the exit strategy is to avoid high inflation due to large-scale excess liquidity in the economy, this paper explores a different aspect of the strategy. Suppose that the central bank increases the short-term policy interest rate during the implementation of the exit strategy. Since the central bank holds the long-term nominal bonds, an increase in the short-term rate may devaluate the central bank's long-term bond holdings. Then, through a portfolio adjustment of the private agent as seen in section 3, the valuation loss of the central bank may affect inflation in the ATR regime. The interesting feature of this mechanism is that an increase in the short-term rate (deflationary policy) may lead to inflation when the central bank's capital is negative. In this case, if the real balance demand is stable, then the central bank is driven to a paradoxical situation where it has to increase the nominal money balance to satisfy the money market.

In this extension, the long-term government nominal bonds are introduced. Specifically, $B_{1,t}$ is the face value of one-period nominal bonds issued at period t and $B_{2,t}$ refers to the face value of two-period nominal bonds issued at period t. The short-term bonds $B_{1,t}$ mature at period $t+1$ and are redeemed for the nominal money value $R_{1,t}, B_{1,t}$ at period $t+1$. The long-term bonds $B_{2,t}$ mature at period $t+2$ and are redeemed for the nominal money value $R_{1,t}B_{1,t}$ at maturity. $R_{1,t}$ and $R_{2,t}$ are the gross nominal interest rates for the short- and long-term bonds, respectively.

At period t, let's suppose that the representative agent sells the premature long-term bonds $(B_{2,t-1})$ and purchases the new long-term bonds $(B_{2,t})$. The premature long-term bonds at period $t(B_{2,t-1})$ are claims for the nominal money value $R_{2,t-1}B_{2,t-1}$ at period $t+1$. Instead of trading the premature long-term bonds, the private agent has the option to invest in the short-term bonds at period t. Since there should be no arbitrage opportunities, then the two risk-free investment choices (premature long-term bonds and short-term bonds) should have the same return. Therefore, the market price of the premature long-term bonds at period t is $R_{2,t-1}R_{1,t}^{-1}$.

By including the long-term bonds, the agent's optimization problem is revised as follows:

$$\max_{\{c_t, M_t, B^A_{1,t}, B^A_{2,t}\}_{t=0}^{\infty}} E_0 \left[\sum_{t=0}^{\infty} \beta^t \log c_t + \chi \log \frac{M_t}{P_t} \right], 0 < \beta < 1 \quad (40)$$

such that

$$c_t + \frac{M_t}{P_t} + \frac{B^A_{1,t}}{P_t} + \frac{B^A_{2,t}}{P_t} \leq y_t - \tau_t + \frac{M_{t-1}}{P_t} + \frac{R_{1,t-1}B^A_{1,t-1}}{P_t} + \frac{R_{2,t-1}R^{-1}_{1,t}B^A_{2,t-1}}{P_t},$$

$$c_t, M_t \geq 0, \forall t \geq, M_{-1} + R_{1,-1}B^A_{1,-1} + R_{2,-1}R^{-1}_{1,0}B^A_{2,-1} > 0,$$

where $B^A_{1,t}$ refers to the agent's holdings of the short- and long-term bonds. If the constant output assumption is maintained as seen in section 3, then the Euler equations are equations (27), (28),[18] and the following additional equation:

$$\frac{1}{R_{2,t}} = E_t\left[\beta^2 \frac{P_t}{P_{t+2}}\right] = \frac{1}{R_{1,t}} E_t\left[\frac{1}{R_{1,t+1}}\right] + COV\left[\frac{\beta}{\pi_{t+1}}, \frac{\beta}{\pi_{t+2}},\right]. \tag{41}$$

The additional Euler equation (41) implies the expectations theory of the term structure of interest rates. In regard to the market clearing condition, the bonds market clearing condition is revised as follows, while the money and goods market clearing conditions remain the same as in the previous sections.

$$B^s_{1,t} = B^A_{1,t} + B^C_{1,t}, \tag{42}$$

$$B^s_{2,t} = B^A_{2,t} + B^C_{2,t}, \tag{43}$$

where $B^s_{1,t}$ refers to the short- and long-term bond supplies and $B^C_{1,t}$ is the central bank's demand for the bonds.[19]

The public-sector model should also be extended. First, the central bank holds the long-term government bonds, while the fiscal authority issues the long-term bonds. Parallel to the agent's case, the central bank sells the premature long-term bonds in the market and purchases the newly issued long-term bonds. Then, the flow budget constraints of the central bank and the fiscal authority are as follows:

$$\frac{B^C_{1,t} - R_{1,t-1}B^C_{1,t-1}}{P_t} + \frac{B^C_{2,t} - R_{2,t-1}R^{-1}_{1,t}B^C_{2,t-1}}{P_t} = \frac{M_t - M_{t-1}}{P_t} + \kappa_t, \tag{44}$$

$$0 = \frac{B_{1,t} - R_{1,t-1}B_{1,t-1}}{P_t} + \frac{B_{2,t} - R_{2,t-1}R^{-1}_{1,t}B_{2,t-1}}{P_t} + s_t - \kappa_t. \tag{45}$$

---

[18]Since the short-term gross interest rate was denoted by R_t in the previous sections, R_t is equivalent to $R_{1,t}$ in this section.

[19]In addition, the definition of the agent's real financial wealth should be revised to include the long-term bonds.

The transfer rule (24) and the fiscal policy rule (25) should be revised with long-term bonds. The revised rules are

$$\kappa_t = \kappa_0 + \gamma_Q(\overline{cap} - b^C_{1,t-1} - b^C_{2,t-1} + m_{t-1}) + \xi_t, \tag{46}$$

$$s_t = \gamma_0 + \gamma_F(b^A_{1,t-1} - b^A_{2,t-1}) + \psi_t. \tag{47}$$

Second, the fiscal authority and central bank decide the maturity structure of their liabilities and assets. Cochrane (2001) showed that the maturity structure of the government nominal debt affects the equilibrium price level sequence. In this model extension, the following maturity structure is suggested:

$$B_{2,t} = \delta B_{1,t}, (\delta \geq 0), \tag{48}$$

$$B^C_{2,t} = (\delta + \mu_t)B^C_{1,t}, \tag{49}$$

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_{\mu t}, (0 \leq \rho_\mu < 1),$$

where δ is a policy parameter, $\varepsilon_{\mu t}$ is white noise, and μ_t stands for the AR(1) exogenous policy shock that affects the central bank's asset maturity structure. In this specification of the maturity structure, the fiscal authority maintains a fixed ratio (δ) between the face values of the short- and long-term bonds. The central bank maintains the same ratio (δ)[20] for its assets in the steady state, while the bank's asset maturity structure deviates from the fixed ratio (δ) when the policy shock μ_t exists.

The aforementioned maturity policy is such that the central bank (the fiscal authority) adjusts the short- and long-term assets (debts) that are outstanding at each time period. Conversely, in Cochrane's (2001) cases with the outstanding long-term bonds, it was assumed that trade and redemption of premature long-term bonds were not allowed. Since this model allows such transactions, the total face value of the outstanding assets is exposed to the valuation risk when the central bank adjusts its asset balances. That is, if the current short-term interest rate ($R_{1,t}$) increases, then the value of the premature long-term bonds decreases through the decreased market price ($R_{2,t-1}R^{-1}_{1,t}$).

[20]The basic results of the model remain the same when the fiscal authority's debt maturity ratio is different from the asset maturity ratio of the central bank.

This setup is appropriate for analyzing issues of the exit strategy. When economic recovery and inflation are imminent, the Federal Reserve System may try to withdraw liquidity from the economy by selling its assets. During that process, it is plausible that the Federal Reserve System will be required to sell premature long-term bonds because a significant portion of the system's assets is contained within long-term bonds. Since the exit strategy increases the short-term interest rate, the valuation loss from trading the premature long-term bonds is relevant in the exit strategy.

By following the same steps as seen in section 3, a linearized dynamic system is constructed for the vector of the endogenous variables $(d\pi_t, db^C_{1,t}, db^A_{1,t})'$. If the policy parameter is a special case of the ATR regime as seen in condition (35), then the surprise inflation is

$$\eta_t = \frac{\pi^2}{(1+\delta)R_1 b_1^C - m}\left(\varepsilon_{\xi t} - \frac{\delta b_1^C}{\pi}\varepsilon_{\theta t}\right), \tag{50}$$

where b_1^C is the steady-state value (real) of the central bank's holdings for the short-term bonds. Note that the solution (50) is equivalent to the solution in section 3 (36) when no long-term bonds are outstanding ($\delta = 0$).

The results show that when the central bank's steady-state capital level is negative ($(1+\delta)R_1 b_1^C - m < 0$), then the positive monetary policy shock ($\varepsilon_{\theta t} > 0$) induces inflation ($\eta_t > 0$) in the ATR regime. This case is a situation where the central bank already lost significantly from risky assets and the fiscal authority has not been compensating the losses. Since the central bank's asset return is negatively related with the short-term policy interest rate, the positive monetary policy shock has a negative effect on the value of the central bank's net liability. Then, the private agent tries to consume more and hold less nominal money, as is shown in section 3, and surprise inflation follows.

The crucial feature of this scenario is that the central bank without fiscal supports cannot play an active role in stabilizing inflation. As the negative return shock of the central bank induces inflation in this case, the central bank is forced to passively increase the nominal money balance in order to satisfy the money-market clearing condition. The initial policy intention of increasing the short-term interest rate is to shrink the central bank's balance sheet and to mitigate inflation, but the central bank's balance sheet inflates even greater in the end. The obvious solution to avoid such a paradoxical result is to systematically recapitalize the central bank by the fiscal authority. In practice, the central bank may avoid the recapitalization with various measures such as selling off long-term bonds before raising the short-term interest rate, or delaying policy tightening to accumulate seigniorage revenue. But changing the central bank's actions due to the balance sheet concern may undermine its ability to stabilize inflation.

It is also true that the central bank can still operate with negative capital. While Jeanne and Svensson (2007) pointed out that the negative capital of the central bank may undermine the bank's independence from the fiscal authority, the results of this section show that negative capital may not be desirable to the central banks, but for a different reason. That is, a tightening monetary policy shock may ignite further inflation when the capital is negative in a certain policy regime. Although our reasoning is different, our analytic results support Goodfriend's (2011) suggestion. That is, this paper shows that the central bank's balance sheet shocks affect inflation when the fiscal authority does not offset the shocks by targeting the central bank's capital. Therefore, policy coordination between the two institutions is indispensable for price stability.

5. Conclusion

Conventional macroeconomic models treat the central bank's balance sheet as superficial information that does not affect the equilibrium. However, this paper shows that quasi-fiscal policies, which alter the central bank's balance sheet, affect the equilibrium inflation in a certain policy regime. In the active transfer rule regime, the transfer rule between the fiscal authority and central bank does not automatically stabilize the central bank's real capital while monetary and fiscal policies are passive. In this policy regime, the central bank's balance sheet shocks, including the losses incurred from the asset holdings, affect inflation via the private agent's portfolio adjustment. Previous studies, which have not considered this possibility, implicitly assume that the transfer rule is always passive. However, in general circumstances, the policy's passivity is not guaranteed. In other words, it can be an illusionary belief that the fiscal authority will always automatically support the central bank's losses considering the actual laws on the central banks.

The crucial assumption needed for these results is that the real value of central banks' net liability has a finite upper bound, which is the present value of seigniorage and transfer earnings. This paper also shows that the condition is satisfied under general circumstances. When the condition is satisfied, an additional equilibrium condition exists, which is referred to as the central bank's net liability valuation formula, and the formula may or may not restrict inflation process, depending on the activeness of the transfer rule.

The economic mechanism underlying the equilibrium in the active transfer rule regime is the private agent's response to the central bank's balance sheet shocks. When a shock occurs to the central bank's returns in this policy regime, the agent tries to adjust her portfolio between the central bank's liability and consumption, thus the shock affects inflation. This mechanism is comparable to the asset pricing relationships, which equate the value of an asset with the present value of the asset's current and future earnings. That is, the central bank's net liability valuation formula is an asset pricing equation where the general price level is the price of the bank's liability with respect to consumption.

By extending the benchmark model, this paper shows that the issues of an exit strategy may affect inflation in undesirable ways. In an active transfer rule regime, the contractionary monetary policy shock induces inflation when the central bank's capital is negative and the central bank cannot successfully unwind an unconventional balance sheet. Therefore, the fiscal authority and central bank should coordinate, by stabilizing the central bank's capital, in order to isolate the perverse effects of balance sheet shocks on inflation.

Appendix 1. Part of the Proof for Proposition 1

Conditions (15) and (16) imply that conditions (17) and (18) hold. By summing the flow budget constraints (12) and (13) over the period from t to $T-1$ after taking the discounted expected value (at period t) of the constraints, the following equations are true for all $T \geq t+1$:

$$E_t[X_{t,T}d_T^C] = d_t^C - \sum_{s=t}^{T-1} E_t\left[X_{t,s}\left(\frac{i_s}{1+i_s}f(y_s,i_s)+\kappa_s\right)\right], \tag{51}$$

$$E_t[X_{t,T}d_T^F] = d_t^F - \sum_{s=t}^{T-1} E_t\left[X_{t,s}(s_s-\kappa_s)\right]. \tag{52}$$

From conditions (15) and (16),

$$d_t^C - \sum_{s=t}^{\infty} E_t\left[X_{t,s}\left(\frac{i_s}{1+i_s}f(y_s,i_s)+\kappa_s\right)\right] \leq 0, \tag{53}$$

$$d_t^F - \sum_{s=t}^{\infty} E_t\left[X_{t,s}(s_s-\kappa_s)\right] \leq 0. \tag{54}$$

As $T \to \infty$ in (51) and (52),

$$\lim_{T\to\infty} E_t[X_{t,T}d_T^C] = d_t^C - \sum_{s=t}^{\infty} E_t\left[X_{t,s}\left(\frac{i_s}{1+i_s}f(y_s,i_s)+\kappa_s\right)\right], \tag{55}$$

$$\lim_{T\to\infty} E_t[X_{t,T}d_T^F] = d_t^F - \sum_{s=t}^{\infty} E_t\left[X_{t,s}(s_s-\kappa_s)\right]. \tag{56}$$

Equations (53)–(56) imply

$$-\infty < \lim_{T\to\infty} E_t[X_{t,T}d_T^C] \leq 0, \tag{57}$$

$$-\infty < \lim_{T\to\infty} E_t[X_{t,T}d_T^F] \leq 0. \tag{58}$$

since $|w_t^A| < \infty$ and conditions (15) and (16) imply $d_t^C, d_t^F > -\infty$. Owing to the transversality condition (5),

$$\lim_{T\to\infty} E_t[X_{t,T}d_T^C] + \lim_{T\to\infty} E_t[X_{t,T}d_T^F] \geqq 0, \tag{59}$$

since $w_T^A = d_T^C + d_T^F$. Therefore,

$$\lim_{T\to\infty} E_t[X_{t,T}d_T^C] = 0, \tag{60}$$

$$\lim_{T\to\infty} E_t[X_{t,T}d_T^F] = 0. \tag{61}$$

Conversely, conditions (60) and (61) imply that assumptions (15) and (16) hold. Suppose that conditions (60) and (61) are true. From the budget constraints, equations (51) and (52) are true. As $T \to \infty$ in equations (51) and (52), conditions (53) and (54) hold by equality. Then, since d_t^C and d_t^F are finite, conditions (15) and (16) are necessarily true. Therefore, conditions (15) and (16) are equivalent to conditions (60) and (61).

Appendix 2. Solution of the Dynamic System in Section 3

In order to arrange the model with a linear dynamic system, this paper linearizes the Fisher equation (28) and the budget constraints (12) and (13). These three equations form a dynamic system in matrix equation (62). The first row of (62) is from the Fisher equation, the second row is from the central bank budget constraint, and the third row is from the fiscal authority budget constraint. The money-market equilibrium condition (27) and the policy rules (23), (24), and (25) are substituted into the three equations. In the coefficient matrices ($\Gamma_0, \Gamma_1, \Phi_0$, and Φ_1), the variables without time index refer to the steady-state values.

$$\underbrace{\begin{bmatrix} 1 & 0 & 0 \\ \varphi_1 & 1 & 0 \\ \varphi_4 & 1 & 1 \end{bmatrix}}_{\Gamma_0} \underbrace{\begin{bmatrix} d\pi_{t+1} \\ db_{t+1}^C \\ db_{t+1}^A \end{bmatrix}}_{x_{t+1}} = \underbrace{\begin{bmatrix} \alpha\beta & 0 & 0 \\ \varphi_2 & \beta^{-1} - \gamma_Q & 0 \\ \varphi_5 & \beta^{-1} - \gamma_Q & \beta^{-1} - \gamma_F \end{bmatrix}}_{\Gamma_1} \underbrace{\begin{bmatrix} d\pi_t \\ db_t^C \\ db_t^A \end{bmatrix}}_{x_t}$$
$$+ \underbrace{\begin{bmatrix} 0 & 0 & 0 \\ \varphi_3 & 1 & 0 \\ 0 & 1 & -1 \end{bmatrix}}_{\Phi_0} \underbrace{\begin{bmatrix} d\theta_{t+1} \\ d\xi_{t+1} \\ d\psi_{t+1} \end{bmatrix}}_{z_{t+1}} + \underbrace{\begin{bmatrix} \beta & 0 & 0 \\ \alpha^{-1}\varphi_2 & 0 & 0 \\ \alpha^{-1}\varphi_5 & 0 & 0 \end{bmatrix}}_{\Phi_1} \underbrace{\begin{bmatrix} d\theta_t \\ d\xi_t \\ d\psi_t \end{bmatrix}}_{z_t} + \underbrace{\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} d\eta_{t+1}}_{\Pi_{t+1}}, \tag{62}$$

where

$$\varphi_1 \equiv \frac{Rb^C - m}{\pi^2} + \frac{\alpha\chi y}{(R-1)^2}, \varphi_2 \equiv \frac{\alpha}{\pi}\left[\frac{\chi y}{(R-1)^2} + b^C\right] - \frac{\alpha\gamma_Q\chi y}{(R-1)^2},$$
$$\varphi_3 \equiv \frac{-\chi y}{(R-1)^2}, \varphi_4 \equiv \frac{Rb^A + Rb^C}{\pi^2}, \varphi_5 \equiv \frac{\alpha}{\pi}(b^A + b^C) - \frac{\alpha\gamma_Q\chi y}{(R-1)^2}.$$

If the vectors x_t and z_t are stacked, then the system (62) becomes equation (63).

$$\underbrace{\begin{bmatrix} d\pi_{t+1} \\ db^C_{t+1} \\ db^A_{t+1} \\ d\theta_{t+1} \\ d\xi_{t+1} \\ d\psi_{t+1} \end{bmatrix}}_{Y_{t+1}} = \underbrace{\begin{bmatrix} \alpha\beta & 0 & 0 & \beta & 0 & 0 \\ \varphi_6 & \beta^{-1}-\gamma_Q & 0 & \varphi_7 & \rho_\xi & 0 \\ \varphi_8 & 0 & \beta^{-1}-\gamma_F & \varphi_9 & 0 & -\rho_\psi \\ 0 & 0 & 0 & \rho_\theta & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_\xi & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_\psi \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} d\pi_t \\ db^C_t \\ db^A_t \\ d\theta_t \\ d\xi_t \\ d\psi_t \end{bmatrix}}_{Y_t}$$

$$+ \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -\varphi_1 & 0 & 0 & \varphi_3 & 1 & 0 \\ \varphi_1-\varphi_4 & 0 & 0 & \varphi_3 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}}_{C} \underbrace{\begin{bmatrix} \eta_{t+1} \\ 0 \\ 0 \\ \varepsilon_{\theta t+1} \\ \varepsilon_{\xi t+1} \\ \varepsilon_{\psi t+1} \end{bmatrix}}_{\zeta_t}, \qquad (63)$$

where

$$\varphi_6 \equiv \varphi_2 - \alpha\beta\varphi_1, \varphi_7 \equiv \rho_\theta\varphi_3 - \beta\varphi_1 + \alpha^{-1}\varphi_2,$$
$$\varphi_8 \equiv \alpha\beta(\varphi_1-\varphi_4) - \varphi_2 + \varphi_5, \varphi_9 \equiv -\rho_\theta\varphi_3 + \alpha^{-1}\varphi_8.$$

The eigenvalues of transition matrix A can be read off from the diagonal elements. By the eigenvector decomposition, matrix A can be decomposed into $P \wedge P^{-1}$ where $\wedge$ is a diagonal matrix with eigenvalues, and P^{-1} can be expressed as matrix (64).

$$P^{-1} = \begin{bmatrix} 1 & 0 & 0 & \frac{\beta}{\alpha\beta-\rho_\theta} & 0 & 0 \\ p_1 & 1 & 0 & p_2 & p_3 & 0 \\ p_4 & 0 & 1 & p_5 & 0 & p_6 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, \qquad (64)$$

where

$$p_1 \equiv \frac{-\varphi_6}{\alpha\beta-\beta^{-1}+\gamma_Q}, p_2 \equiv \frac{1}{\beta^{-1}-\gamma_Q-\rho_\theta}\left(\varphi_7 - \frac{\beta\varphi_6}{\alpha\beta-\beta^{-1}+\gamma_Q}\right),$$

$$p_3 \equiv \frac{\rho_\xi}{\beta^{-1} - \gamma_Q - \rho_\xi}, p_4 \equiv \frac{-\varphi_8}{\alpha\beta - \beta^{-1} + \gamma_F},$$

$$p_5 \equiv \frac{1}{\beta^{-1} - \gamma_F - \rho_\theta}\left(\varphi_9 - \frac{\beta\varphi_8}{\alpha\beta - \beta^{-1} + \gamma_F}\right), p_6 \equiv \frac{-\rho_\psi}{\beta^{-1} - \gamma_F - \rho_\psi}.$$

The solution of the system is derived by eliminating the explosive eigenvalues. If the j^{th} eigenvalue is explosive, then the solution is such that $P^{j\cdot}Y_t = 0$, where $P^{j\cdot}$ refers to the j^{th} row of P^{-1}. The linear mappings from the exogenous shock to the endogenous forecast error are given by $P^{j\cdot}C\zeta_t = 0$.

References

Bernanke, B. S. 2009. "The Federal Reserve's Balance Sheet: An Update." Speech at the Federal Reserve Board Conference on Key Developments in Monetary Policy, Washington, DC, October 8.

Berriel, T. C., and S. Bhattarai. 2009. "Monetary Policy and Central Bank Balance Sheet Concerns." *B.E. Journal of Macroeconomics: Contributions in Macroeconomics* 9 (1): Article 1.

Canzoneri, M. B., R. E. Cumby, and B. T. Diba. 2001. "Is the Price Level Determined by the Needs of Fiscal Solvency?" *American Economic Review* 91 (5): 1221–38.

Chung, H., T. Davig, and E. M. Leeper. 2007. "Monetary and Fiscal Policy Switching." *Journal of Money, Credit and Banking* 39 (4): 809–42.

Cochrane, J. H. 2001. "Long-Term Debt and Optimal Policy in the Fiscal Theory of the Price Level." *Econometrica* 69 (1): 69–116.

———. 2005. "Money as Stock." *Journal of Monetary Economics* 52 (3): 501–28.

Goodfriend, M. 2011. "Central Banking in the Credit Turmoil: An Assessment of Federal Reserve Practice." *Journal of Monetary Economics* 58 (1): 1–12.

Goodhart, C. A. E. 1988. *The Evolution of Central Banks.* Cambridge, MA: MIT Press.

Jeanne, O., and L. E. O. Svensson. 2007. "Credible Commitment to Optimal Escape from a Liquidity Trap: The Role of the Balance Sheet of an Independent Central Bank." *American Economic Review* 97 (1): 474–90.

Klüh, U., and P. Stella. 2008. "Central Bank Financial Strength and Policy Performance: An Econometric Evaluation." IMF Working Paper No. 08/176.

Leeper, E. M. 1991. "Equilibria under 'Active' and 'Passive' Monetary and Fiscal Policies." *Journal of Monetary Economics* 27 (1): 129–47.

Mackenzie, G. A., and P. Stella. 1996. "Quasi-Fiscal Operations of Public Financial Institutions." IMF Occasional Paper No. 142.

Sargent, T. J., and N. Wallace. 1981. "Some Unpleasant Monetarist Arithmetic." *Quarterly Review* (Federal Reserve Bank of Minneapolis) 5 (3, Fall): 1–17.

Sims, C. A. 1994. "A Simple Model for Study of the Determination of the Price Level and the Interaction of Monetary and Fiscal Policy." *Economic Theory* 4 (3): 381–99.

———. 2001. "Solving Linear Rational Expectations Models." *Computational Economics* 20 (1): 1–20.

———. 2003. "Fiscal Aspects of Central Bank Independence." Unpublished Manuscript, Princeton University.

Stella, P., and Å. Lönnberg. 2008. "Issues in Central Bank Finance and Independence." IMF Working Paper No. 08/37.

Woodford, M. 2001. "Fiscal Requirements for Price Stability." *Journal of Money, Credit and Banking* 33 (3): 669–728.

———. 2003. "*Interest and Prices*." Princeton, NJ: Princeton University Press.

The Federal Reserve's Balance Sheet and Earnings: A Primer and Projections*

Seth Carpenter, Jane Ihrig, Elizabeth Klee, Daniel Quinn, and Alexander Boote
Federal Reserve Board

Over the past few years, the Federal Reserve's use of unconventional monetary policy tools has received a vast amount of public attention, from discussing how these asset purchases have put downward pressure on longer-term interest rates and thus supported economic activity to evaluating the implications for Federal Reserve remittances to the Treasury and the effect on monetary and fiscal policy. As the economic recovery has gained some momentum of late, the focus has turned to issues associated with the normalization of monetary policy. In this paper, we begin by providing a primer for the Federal Reserve's balance sheet and income statement. With that foundation in place, we then consider a variety of scenarios consistent with statements by Federal Reserve officials about how the FOMC will normalize policy, including whether to sell mortgage-backed securities, whether to change the composition of Federal Reserve liabilities, and the timing of lifting the federal funds rate off from the zero lower bound. In each of these scenarios, we discuss the implications of these normalization policies on the size and composition of Federal Reserve asset and liability holdings and on remittances of earnings to the Treasury, which capture the interest rate risk of these normalization policies. We show that under a baseline

*The authors are staff economists and research assistants in the Division of Monetary Affairs, Board of Governors of the Federal Reserve System, Washington, D.C. 20551 U.S.A. We thank James Clouse, Bill English, Michelle Ezer, Don Hammond, Lawrence Mize, Julie Remache, Viktors Stebunovs, Lisa Stowe, Jeff Moore, Ari Morse, Brett Schulte, Joe Kachovec, and three anonymous referees for thoughtful comments and assistance. The views 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.

normalization strategy described by policymakers, the balance sheet should slowly return to a more normal composition and size, while remittances should remain sizable. With some alternative normalization plans, especially if faced with high interest costs, remittances could drop to zero for some time.

JEL codes: E52, E58, E47.

1. Introduction

In response to the financial crisis that began in 2007 and the subsequent recession, the Federal Reserve employed a variety of non-traditional monetary policy tools that garnered a vast amount of public discussion. Some discussion focused on the expanding size and changing composition of the Federal Reserve's balance sheet and, specifically, the Federal Reserve's holdings of securities in the System Open Market Account (SOMA) (Federal Reserve Bank of New York 2013). This expansion led to discussions about the effects of unconventional monetary policy on interest rates (Krishnamurthy and Vissing-Jorgensen 2011, Li and Wei 2013). In addition, other authors highlighted implications for Federal Reserve transfers to the Treasury ("remittances"), the effect on monetary and fiscal policy (Rudebusch 2011, Greenlaw et al. 2013), and the independence of the Federal Reserve from political pressure (Christensen, Lopez, and Rudebusch 2013).

More recently, as the economic recovery has gained some momentum, the discussion has turned to questions about the normalization of monetary policy. In various venues, Federal Open Market Committee (FOMC) participants have expressed their views about normalizing the stance of monetary policy. In particular, the June 2013 FOMC minutes provided some discussion on policy normalization and the long-run composition of the balance sheet, while FOMC statements clearly tie the rise in the federal funds rate to the outlook for unemployment and inflation. In this paper, we consider how the Federal Reserve's balance sheet, and the income that derives from the balance sheet, might evolve under a variety of assumptions about the path of monetary policy and approaches to the normalization of policy. For example, we consider the June 2011 exit principles that included sales of mortgage-backed securities (MBS) as part of the normalization process, as well as the more recent information laid out in the June 2013 minutes that suggests that such sales would not be a prominent part of the early stages of policy normalization. In addition, given the evolving views in markets about the likely timing of the first increase in the federal funds rate, we consider a scenario where the date of liftoff is pushed out, consistent with some variant of quantitative forward guidance related to an unemployment rate or inflation threshold, and analyze the effect of that timing for the path of the balance sheet. Finally, we discuss some of the possible implications for Federal Reserve expenses from choosing different mixes of Federal Reserve liabilities (known as "reserve-draining tools") during the normalization process.

The scenarios presented here do not provide an exhaustive range of options that the FOMC could use to remove monetary policy accommodation. They do, however, show how many tools, in isolation, can aid the Committee in reducing the size of the balance sheet and boost short-term interest rates.[1] With these scenarios in mind, one can then see the impact of any convex combination of tools that the Committee may choose during the normalization process.

In analyzing each normalization scenario, we report the length of time until the Federal Reserve's balance sheet returns to a normal size. We also project how MBS holdings will evolve, given that holdings of MBS are a particularly novel development for the Federal Reserve and minutes from FOMC meetings suggest that their acquisition has been a source of some debate. In addition, we look at the interest rate risk of different exit strategies that appear to be under consideration. Such considerations may be important if, as Greenlaw et al. (2013) suggest, a period of zero remittances results in negative political pressures.

The remainder of the paper is organized as follows. Section 2 provides a primer on the Federal Reserve's balance sheet and income statement. Section 3 outlines the scenario assumptions used as inputs to the projections of the balance sheet. The baseline balance sheet and income projections are discussed in section 4. Section 5 considers the alternative normalization policies. Section 6 provides the sensitivity analysis. Section 7 concludes.

[1] See Ihrig et al. (2012) for how to link the size of the balance sheet to monetary policy accommodation.

2. The Federal Reserve's Balance Sheet, Income Statement, and Valuation of the SOMA Portfolio

In this section, we review key balance sheet components in our projections, as well as the income generated from the balance sheet. We also provide some historical context for the evolution of these items.

2.1 The Federal Reserve's Balance Sheet

Our discussion of the Federal Reserve's balance sheet will refer to the consolidated balance sheets of the twelve individual Reserve Bank balance sheets.[2] In reality, the accounting that will be discussed below is done at the Reserve Bank level; however, for simplicity, we focus on the Federal Reserve System's aggregate balance sheet.

Like any balance sheet, the Federal Reserve has assets on one side of the balance sheet, which must equal liabilities plus capital on the other side. As shown in table 1, at the end of 2006, total assets of the Federal Reserve were $874 billion, with the single largest asset item being the SOMA portfolio, at about $780 billion. Prior to the financial crisis, the domestic SOMA portfolio comprised only Treasury securities, of which roughly one-third were Treasury bills and two-thirds were Treasury coupon securities. On the other side of the balance sheet, the largest liability item was paper currency, or Federal Reserve notes (FR notes), at about $785 billion.

With the lending that took place during the financial crisis, for a time, the amount outstanding in the credit and liquidity facilities surpassed the size of the SOMA portfolio. As of December 25, 2013, however, the SOMA portfolio was again the largest asset item, and it had grown to $3.8 trillion because of the asset purchase programs. On the liability side of the balance sheet, FR notes, at about $1.2 trillion, were no longer the largest liability item. Instead, as the FOMC increased its asset purchases, reserve balances increased correspondingly to a level of about $2.5 trillion.

[2]The Board of Governors does not hold assets and liabilities in the same way that the Reserve Banks do. Section 10 of the Federal Reserve Act authorizes the Board to levy semi-annually upon the Reserve Banks, in proportion to their capital stock and surplus, an assessment sufficient to pay its estimated expenses for the half of the year succeeding the levying of such assessment, together with any deficit carried forward from the preceding half-year.

Table 1. Federal Reserve's Balance Sheet

Balance Sheet End-2006 $Billion				**Balance Sheet End-2013 $Billion**			
Assets		**Liabilities**		**Assets**		**Liabilities**	
SOMA	779	Deposits of Dep. Inst.	13	SOMA	3,763	Deposits of Dep. Inst.	2,451
Other Assets	95	Federal Reserve Notes	783	Other Assets	270	Federal Reserve Notes	1,195
		Other Liabilities	48			Other Liabilities	332
		Total Capital	31			Total Capital	55

Source: H.4.1. statistical release.

The next few sub-sections review the key components of the Federal Reserve's balance sheet and how they have changed.[3]

2.1.1 The SOMA Portfolio: Composition, Size, and Maturity Structure

Over most of the post-war period, the SOMA portfolio was the largest asset item on the Federal Reserve's balance sheet.[4] During that time, the SOMA portfolio essentially held Treasury securities; however, the portfolio has held other types of securities over the course of its history.[5] For example, from 1971 to 1981, the Federal Reserve purchased limited quantities of agency securities; the last of these securities matured in the early 2000s, and none was purchased until 2008.[6]

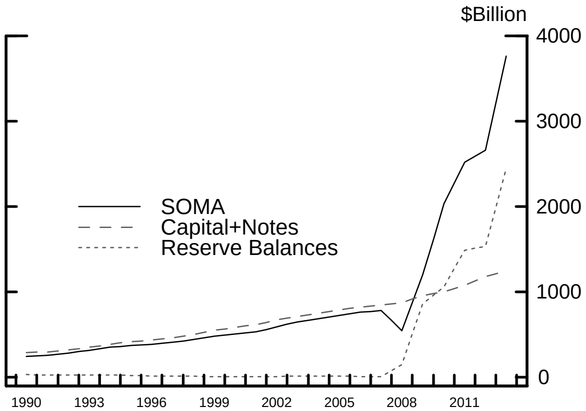
[3]For a description of additional components of the balance sheet, see the interactive guides to the H.4.1 tables at http://www.federalreserve.gov/monetarypolicy/bst_fedsbalancesheet.htm or the *Financial Accounting Manual for Reserve Banks* at http://www.federalreserve.gov/monetarypolicy/files/bstfinaccountingmanual.pdf.

[4]For a description of the Federal Reserve's balance sheet prior to World War II, see *Banking and Monetary Statistics, 1914–1941*, at http://fraser.stlouisfed.org/title/?id=38.

[5]Refer to Edwards (1997).

[6]Refer to Meltzer (2010).

Figure 1. SOMA, Capital + FR Notes, and Reserve Balances



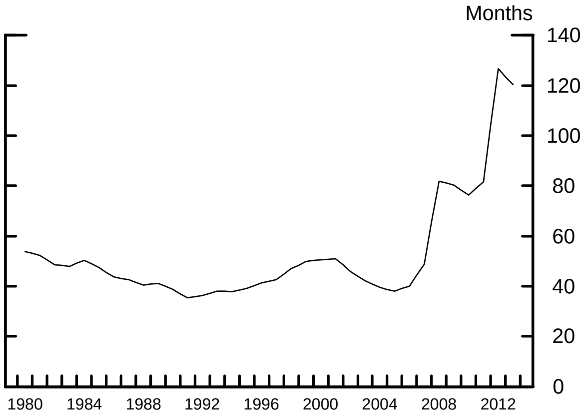
Source: H.4.1 statistical release.

Historically, the size of the SOMA portfolio—and the balance sheet, more generally—reflected growth in FR notes and Reserve Bank capital. When currency is put into circulation, it is shipped to a depository institution, and that institution's account at the Federal Reserve is debited by an equivalent amount. Because currency outstanding tends to trend upward, over time currency growth would tend to reduce the amount of reserve balances in the banking system. The Federal Reserve would purchase securities in open-market operations to offset this drain of reserves. On net, therefore, the growth rate of currency tended to drive the size of the balance sheet. Similarly, when a depository institution is required to subscribe to a larger amount of Federal Reserve capital or the Federal Reserve adds to its surplus account, the result would be, all else equal, a reduction in reserve balances.[7] As a result, the SOMA portfolio must increase to offset these increases as well, creating a larger balance sheet overall.

This historical pattern is illustrated in figure 1. As can be seen, through 2007, both the SOMA portfolio and currency and capital

[7]As will be more fully explained later in the paper, each member bank of a Reserve Bank is required to subscribe to the capital of its district Reserve Bank in an amount equal to 6 percent of its own capital stock.

Figure 2. Weighted Average Maturity of SOMA



Source: Federal Reserve Bank of New York.
Notes: Includes only nominal Treasury securities.

trended upward together. When the asset programs began in late 2008 and early 2009, and continuing through the second round of purchases in 2010 and 2011, the SOMA portfolio increased markedly and at a rate that far outpaced the growth of currency and capital. With the initiation of the maturity extension program in 2011, the size of the portfolio remained roughly constant; however, as depicted in figure 2, the weighted average maturity of Treasury securities in the SOMA portfolio increased markedly. From a longer perspective, over time, the SOMA portfolio has had a range of maturities of Treasury securities in its holdings.[8] Prior to the financial crisis, the Open Market Trading Desk (the Desk) tended to purchase securities across the entire yield curve to avoid distorting the yield curve. However, after the start of the financial crisis, the maturity of Treasury coupon securities in the SOMA portfolio lengthened notably, reflecting the runoff in bills to sterilize the credit and liquidity programs in 2008, and the purchase of longer-dated securities more recently.

[8]In the weekly H.4.1 statistical release, in addition to the Federal Reserve's balance sheet, the maturity distribution of asset holdings is also published.

2.1.2 Deposits of Depository Institutions

Deposits of depository institutions include all depository institutions' balances at the Federal Reserve that are used to satisfy reserve requirements and balances held in excess of balance requirements. Deposits of depository institutions grew dramatically through the crisis, and are currently quite elevated by historical standards. When we refer to "reserve balances," we are using the "deposits of depository institutions" concept. These deposits represent funds that depository institutions own; they are a liability of the Reserve Bank, but an asset of the depository institution. These funds are also used for payment system settlement; for example, a payment from one bank to another (or from one bank's customer to the customer of a different bank) typically results in a debit to the paying bank's account and a credit to the receiving bank's account. Lending of reserve balances and payment activity result only in a movement of reserve balances from one depository institution's account at the Federal Reserve to another institution's account; the aggregate quantity is unchanged.

2.1.3 Federal Reserve Notes

Federal Reserve notes, or currency, are a liability of the Federal Reserve. As a practical matter, the Federal Reserve does not determine the quantity of currency outstanding. Instead, when a depository institution wants to hold currency in its vault or automatic teller machines in order to meet customer needs, it requests a shipment from its Federal Reserve Bank. When that shipment is made, the depository institution's reserve account at the Reserve Bank is debited by the amount of the currency shipment. One important source of demand for U.S. currency is from overseas. Although it is impossible to know with certainty what portion of currency outstanding is outside of the United States, estimates suggest that the fraction is one-half or more.[9] Prior to the financial crisis, currency was the largest liability item on the Federal Reserve's balance sheet.

[9] Refer to Judson and Porter (1996).

2.1.4 Capital Paid In, Surplus, and Interest on Federal Reserve Notes Due to U.S. Treasury

The capital of the Reserve Banks is different from the capital of other institutions.[10] It does not represent controlling ownership as it would for a private-sector firm. Ownership of the stock is required by law, the Reserve Banks are not operated for profit, and the stock may not be sold, traded, or pledged as security for a loan. As stipulated in section 5 of the Federal Reserve Act, each member bank of a Reserve Bank is required to subscribe to the capital of its district Reserve Bank in an amount equal to 6 percent of its own capital stock. Of this amount, half must be paid to the Federal Reserve Banks (referred to as capital paid in) and half remains subject to call by the Board of Governors. This capital paid in is a required assessment on the member banks and its size changes directly with the capital of the member banks. Also stipulated by law is that dividends are paid at a rate of 6 percent per year. Over the past decade, reflecting increases in capital at member banks, Reserve Bank capital has grown at an average rate of almost 15 percent per year. In addition, Reserve Banks have surplus capital, which reflects withheld earnings, and Federal Reserve Bank accounting policies stipulate that the Reserve Banks withhold earnings sufficient to equate surplus capital to capital paid in. As a result, as capital of member banks grows through time, capital paid in grows in proportion. Because surplus is set equal to capital paid in, it likewise grows at the same rate as member bank capital.

2.1.5 Deferred Asset

One liability item is distinct from the others. Under the Federal Reserve's remittance policy, the Federal Reserve remits all net income to the U.S. Treasury, after expenses and dividends and allowing for surplus to be equated to capital paid in. As those earnings accrue, they are recorded on the Federal Reserve's balance sheet as

[10]See the *Financial Accounting Manual for Federal Reserve Banks*, which reports the accounting standards that should be followed by the Federal Reserve Banks, at http://www.federalreserve.gov/monetarypolicy/files/bstfinaccountingmanual.pdf, pages 1–68.

"Interest on Federal Reserve notes due to U.S. Treasury." In the event that earnings only equal the amount necessary to cover operating costs, pay dividends, and equate surplus to capital paid in, this liability item would fall to zero because there are no earnings to remit and payments to the Treasury would be suspended. If earnings are insufficient to cover these costs—that is, there is an operating loss in some period—then no remittance is made until earnings, through time, have been sufficient to cover that loss. The value of the earnings that need to be retained to cover this loss is called a "deferred asset" and is booked as a negative liability on the Federal Reserve's balance sheet under the line item "Interest on Federal Reserve notes due to U.S. Treasury." A deferred asset is an asset in the sense that it reflects a reduction of future liabilities to the U.S. Treasury.

One consequence of the current implementation of Federal Reserve Bank accounting policy is that the recording of a deferred asset implies that Reserve Bank capital does not decline in the event of an operating loss. From time to time, individual Reserve Banks have reported a deferred asset; for example, as shown on the H.4.1 statistical release from November 3, 2011, the Federal Reserve Bank of New York recorded a deferred asset that week and the subsequent week.[11] However, by the third week, remittances had cumulated to a sufficient level to be able to pay off the deferred asset. More generally, it has never been the case that the Federal Reserve System as a whole has suspended remittances to the Treasury for a meaningful period of time because of operating losses.

Because there has never been a deferred asset of any significant size, there is little guidance as to the whether or not there is a limit to the potential size of the asset. It may be plausible to assume that it would not be allowed to exceed the value of all future earnings, possibly in present discounted terms, given the fact that it is paid down through future earnings. As will be clear in the following projections, a scenario that would result in a deferred

[11] In November 2011, the Maiden Lane accounts, which are marked to market and consolidated onto the balance sheet of the Federal Reserve Bank of New York (FRBNY), were revalued and resulted in an unrealized loss that required the Federal Reserve Bank of New York to record a deferred asset. Over time, the FRBNY's loans to the Maiden Lane limited liability companies were repaid in full, with interest.

asset in excess of the present value of future earnings is difficult to contemplate.

Some foreign central banks do not record deferred assets and instead use different accounting policies. For example, many foreign central banks smooth remittances each year, by transferring an average amount of net income back to the government and saving the "excess" net income for times with negative shocks. Other foreign central banks allow for negative remittances—that is, transfers *from* rather than *to* the government—if the loss is too large. The infusion of funds from their governments in cases of large negative shocks avoids deferred assets for these institutions. One example of a central bank with a form of a deferred asset is the Czech National Bank. This institution has operated for a number of years with a negative equity position and zero remittances. We will return to this balance sheet line item in the projections, as we see what policy levers may induce a deferred asset.

2.2 The Federal Reserve's Income Statement

As the Federal Reserve's balance sheet has expanded in recent years, the income derived from the balance sheet has also grown, though the key line items from the balance sheet that generated this income are the same. As shown in table 2, net income in both 2006 and 2013 was driven by interest income from the SOMA portfolio. Despite the difference in magnitude, in both years, SOMA interest income was more than 95 percent of total income. That said, SOMA interest income grew substantially over this period as the SOMA portfolio expanded. Interest expense, on the other hand, was minimal in both years. In particular, FR notes are a large liability without an associated interest expense. And, although the Federal Reserve has paid interest on reserve balances since October 2008, this liability item has incurred little interest expense because the IOER (interest on excess reserves) rate has been at 25 basis points since December 2008. In both years, other items in the income statement were similar. In total, remittances to the Treasury were positive in both years, but much larger in 2013 because of the expanded SOMA portfolio.

The next few sub-sections review the key line items of the Federal Reserve's income statement in more detail.

Table 2. Federal Reserve's Income and Expense

Income and Expense, 2006 $Billion				**Income and Expense, 2013 $Billion**			
Income		**Expense**		**Income**		**Expense**	
Interest Income	37	Interest Expense	1	Interest Income	90	Interest Expense	5
Other Income	2	Other Expense	4	Other Income	1	Other Expense	7
		Additions/ Deductions, Dividends, and Transfers	4			Additions/ Deductions, Dividends, and Transfers	2

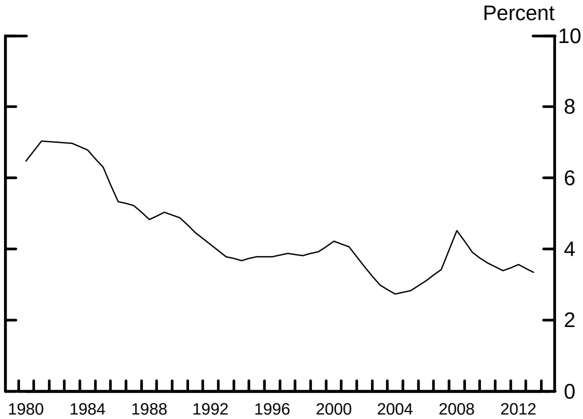
Source: Federal Reserve annual report and press release titled "Reserve Bank Income and Expense Data and Transfers to the Treasury for 2013" (January 10, 2014).

2.2.1 SOMA Interest Income

As noted above, income on the securities held in the SOMA portfolio constitutes the vast majority of interest income. SOMA interest income primarily reflects the size of the portfolio and the weighted average coupon (WAC) of the portfolio, less any amortized net premiums paid on securities.[12] Prior to the financial crisis, the size of the portfolio increased steadily at a moderate rate. With the adoption of the asset programs, the securities portfolio expanded rapidly and now stands at a level noticeably above its longer-run trend. The WAC, as shown in figure 3, fluctuated over time, rising and falling with the market rates and the SOMA portfolio's holdings. This pattern primarily reflects the fact that the Federal Reserve reinvests maturing Treasury securities at auction, and the coupon at auction tends to be in line with market rates. Although the asset purchase programs resulted in a significant accumulation of longer-term debt in recent years, much of it was issued in a low interest

[12]SOMA interest income is defined as the rate of return on the portfolio (the product of the size of the portfolio times the WAC) minus amortized net premiums. Net premiums, though important in deriving the precise value of interest income, will not be a primary driver of the contour of the projections of interest income.

Figure 3. Weighted Average Coupon of SOMA



Source: Federal Reserve Bank of New York.
Notes: Includes only nominal Treasury securities.

rate environment and, therefore, the WAC of the portfolio decreased somewhat.

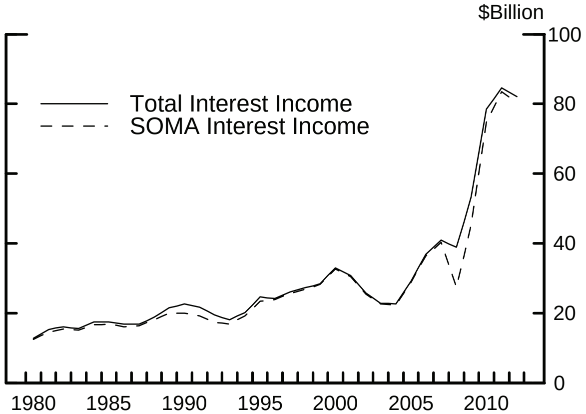
Putting the size of the portfolio and the WAC of the portfolio together, as shown in figure 4, interest income climbed at a moderate pace in the years prior to the financial crisis, primarily because of the steady increase in the size of SOMA, which rose in line with the growth of FR notes and capital. Beginning in 2009, interest income from the portfolio rose noticeably as large-scale asset purchases increased the size of the portfolio.

2.2.2 Interest Expense

With the introduction of interest on reserves in the fall of 2008 and the concurrent rise in the level of reserve balances, interest expense rose. As mentioned above, the IOER rate has been 25 basis points since December 2008, and as a result, even with a substantial volume of reserve balances, interest expense from reserve balances has been low compared with interest income and was roughly $5 billion in 2013.

In addition to interest expense from reserve balances, there is also interest expense from reverse repurchase agreements (RRPs), mostly

Figure 4. Interest Income



Source: Annual report of the Federal Reserve Board of Governors.

generated by the foreign repurchase agreement (RP) pool.[13,14] Interest rates paid on the foreign RP pool are generally in line with market rates, and when reserve balances are relatively low, interest expense on the foreign RP pool can represent a large share of total interest expense.

Reverse repurchase agreements with primary dealers and other institutions and the Term Deposit Facility (TDF) also have associated interest expense. In addition to the primary dealers, the Federal Reserve selected money-market mutual funds, the Federal Home Loan Mortgage Corporation (Freddie Mac), the Federal National Mortgage Association (Fannie Mae), and some banks as potential counterparties for RRPs (both overnight and term). In contrast

[13]Before December 13, 2002, repo transactions were conducted as matched sale-purchase transactions, where the Federal Reserve sold a security with an agreement to purchase it again at a later date. However, because matched sale-purchase transactions were accounted for as an outright sale rather than as a financing transaction the way reverse repurchase agreements are, the transactions did not result in interest expense.

[14]Every business day, the Federal Reserve conducts overnight reverse repos with foreign central banks that hold dollars in their accounts at the Federal Reserve Bank of New York. These transactions are one of the services that central banks provide one another to facilitate their international operations.

to the RRPs, only banks are counterparties in TDF transactions. Although the Federal Reserve has developed the capability of conducting large-scale operations in either RRPs or the TDF, these operations have been only in the testing phase to date, and as a result, interest expense associated with these operations has been minimal.

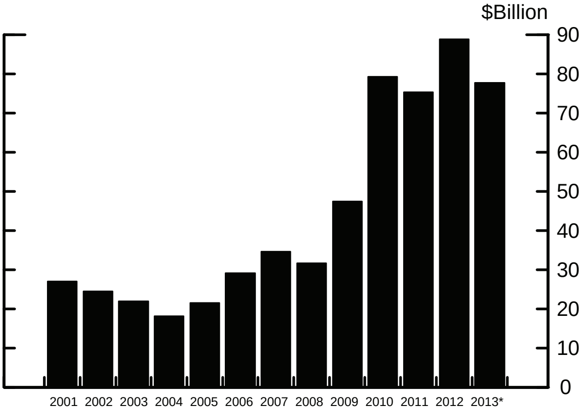
2.2.3 Capital Gain (Loss)

Under Federal Reserve accounting rules, a Federal Reserve Bank realizes gains or losses on a security only when the security is sold. At sale, the Federal Reserve's gain or loss is the market value minus the par value and unamortized net premiums on the security. Historically, the Federal Reserve did not generally sell securities, because the secular growth in currency resulted in a need for a long-term increase in securities holdings. In 2008, however, the Desk did sell some securities to offset the expansion of the balance sheet that resulted from the introduction of the liquidity facilities at the early stages of the financial crisis. In that year, the Federal Reserve realized a capital gain of roughly $3 billion because market rates had fallen, pushing up the market price of the securities sold. With the maturity extension program, the Federal Reserve also sold securities; in 2011, these sales realized a $2.3 billion capital gain.

2.2.4 Payment of Dividends, Transfers to Surplus, and Interest on Federal Reserve Notes Due to U.S. Treasury

As noted above, member banks are required to subscribe to the capital stock of the Reserve Banks, and the Federal Reserve Act stipulates that the Federal Reserve pay a 6 percent dividend on this capital. Under policy prescribed by the Board of Governors, excess earnings are retained as surplus capital in an amount equal to capital paid in. Before remittances to the Treasury are made, dividends are paid and earnings are retained to equate surplus to capital paid in. Dividends are paid even if remittances to the Treasury would be zero. As discussed earlier, in the event that earnings fall short of the amount necessary to cover operating costs, pay dividends, and equate surplus to capital paid in, the Federal Reserve books a liability of "Interest on Federal Reserve notes due to U.S. Treasury." This line item is recorded in lieu of reducing the Reserve Bank's surplus.

Figure 5. Federal Reserve Distributions to the U.S. Treasury



Source: Annual report of the Federal Reserve Board of Governors.
*Preliminary unaudited estimate; see http://www.federalreserve.gov/newsevents/press/other/20140110a.htm.

2.2.5 Remittances to the Treasury

Each week, the Federal Reserve remits any earnings in excess of operating expenses and dividends to the U.S. Treasury.[15] The use of these funds is stipulated in the Federal Reserve Act, which states:

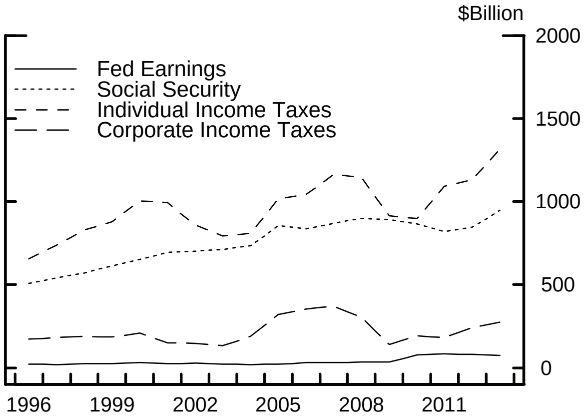
> The net earnings derived by the United States from Federal Reserve banks shall, in the discretion of the Secretary, be used to supplement the gold reserve held against outstanding United States notes, or shall be applied to the reduction of the outstanding bonded indebtedness of the United States under regulations to be prescribed by the Secretary of the Treasury.[16]

Over time, as shown in figure 5, annual remittances remained in a relatively small range, averaging about $25 billion in the years

[15] Occasionally, statutory transfers occur, which mandate that the Federal Reserve transfer a portion of its surplus to the Treasury. The last time this occurred was in 2000, when approximately $3.8 billion held in the surplus account was transferred to the Treasury.

[16] Federal Reserve Act, Section 7, Use of Earnings Transferred to the Treasury, 12 USC 290, sub-section (b).

Figure 6. Selected Treasury Receipts



Source: U.S. Treasury Bulletin.

immediately preceding the financial crisis. During the crisis, as Federal Reserve income increased notably, so did remittances to the Treasury. Still, remittances remained a relatively small share of government receipts—dwarfed by individual income and corporate income taxes, as shown in figure 6, and about in line with customs deposits (not shown).

3. Projections Assumptions

In order to construct projections of the Federal Reserve's balance sheet, assumptions about many of the details of the macroeconomy as well as the Federal Reserve's balance sheet and its evolution must be made. In addition, the projections in this paper are constructed to be consistent with the Federal Reserve accounting principles discussed in section 2.[17] The following sub-sections review key assumptions made to project the balance sheet and income.

[17] The Federal Reserve's accounting principles are published on the website of the Board of Governors of the Federal Reserve: http://www.federalreserve.gov/monetarypolicy/files/bstfinaccountmanual.pdf.

3.1 Scenario Assumptions and Results Overview

Our projections rely on the FOMC's guidance regarding monetary policy normalization principles, the forecasts in the February 2014 primary dealer survey conducted by the Federal Reserve Bank of New York, and the December 2013 and February 2014 Blue Chip forecasts. In the near term, we assume large-scale asset purchases that are in line with the median projection from the dealer survey, with purchases in 2013 and 2014 totaling about $1.5 trillion. Consistent with the June 2011 FOMC "exit principles," which were detailed in the June 2011 FOMC meeting minutes, we assume that the first step to normalize the stance of monetary policy involves the FOMC allowing SOMA holdings to mature or prepay without reinvestment. Beyond that first move, we analyze a variety of alternative normalization policies mentioned above. A summary of the key results is shown in table 3.

In the baseline projection, we assume no MBS sales. The size of the SOMA portfolio will normalize by June 2021. Despite the normalization of the size of the portfolio, the composition of the portfolio will still reflect the non-traditional policy choices; at the end of our projection period in 2025, over $500 billion of MBS will remain on the Federal Reserve's books. The amount of these MBS holdings even at this late date is still large, and residual sales would most likely take some careful consideration if sales were desired. Annual remittances to the Treasury are projected to remain sizable over the near term and cumulate from 2009 through 2005 to about $920 billion. Overall, this scenario suggests that large-scale asset purchases will have a net positive effect on income relative to a scenario with no purchases, but the Federal Reserve will continue to hold sizable MBS for some time.

The second scenario considers MBS sales. Under the June 2011 exit strategy principles, sales of MBS were included because of a desire to return to a Treasury-only portfolio.[18] Sales of MBS over four years accelerate the date of normalizing the size of the portfolio by about two years relative to the scenario with no MBS sales.

[18]In the minutes of the April 2011 FOMC meeting, the reason for selling MBS was to "minimize the extent to which the SOMA portfolio might affect the allocation of credit across sectors of the economy."

Table 3. Summary of Alternative Normalization Policies

	SOMA Size Normalizes	SOMA Composition Normalizes	2025 MBS Holdings	2009–2025 Cumulative Remittances	Trough Remittances (Date)
	Date		$Billion		
Baseline	Jun. 2021	Aug. 2022	$538	$918	$18 (2018)
MBS Sales	May 2019	Aug. 2020	$0	$820	$0 (2017–2020)
Later Liftoff	Nov. 2021	Nov. 2022	$612	$989	$24 (2019)
Reserve-Draining Tools +50bp	Jun. 2021	Aug. 2022	$538	$875	$11 (2018)
Higher Interest Rates +200bp	—	—	—	—	—
Baseline	Sep. 2021	Aug. 2022	$615	$791	$0 (2017–2020)
MBS Sales	Aug. 2019	Jan. 2021	$0	$634	$0 (2016–2023)

However, sales of MBS would also likely result in realized capital losses on the MBS, an outcome that would most likely reduce annual remittances to zero for a few years. In pursuing this normalization strategy, the FOMC presumably would need to evaluate, among other considerations, the trade-off of quickly reducing MBS holdings to zero with the possibility that remittances could be halted. In addition, seasoned MBS may have a coupon that is very different from prevailing market interest rates, suggesting that these MBS would need to be sold in a less liquid market than the one in which they were purchased, which might also be seen as risking unnecessary volatility in these fixed-income markets at the critical point when the FOMC is trying to firm the stance of policy.[19]

The third scenario explores a policy option that was discussed in early 2014. As the unemployment rate began to decline toward 6.5 percent, the Committee adjusted the quantitative thresholds that dictated the forward guidance on the liftoff of the federal funds rate to language that would signal an extended period of time before raising short-term interest rates.[20] If this guidance implied a later liftoff than what is in the baseline scenario, this would delay the date of normalization of the size of the balance sheet somewhat. Moreover, this alternative path for the balance sheet combined with a different path for interest rates would have implications for Federal Reserve income and, as a result, remittances to the Treasury. In our analysis, a delay in liftoff would boost remittances but result in more MBS holdings at the end of the projection period, implying holding these non-traditional assets on the balance sheet for longer, or having to sell more residual MBS at some date in the future.

Finally, we examine the use of term reserve-draining tools. The baseline analysis does not explicitly model reserve-draining tools. One interpretation of this assumption is that no such tools are

[19] "Seasoned" MBS, or MBS that have been issued sometime prior, would need to be sold in the specified pool MBS market. As discussed in Vickrey and Wright (2013), and detailed in Friewald, Jankowitsch, and Subrahmanyam (2014), the transaction costs of selling these securities far exceed those in the TBA market, where the securities were purchased. Executing a high volume of trades in any market with high transaction costs could potentially present difficulties for market functioning.

[20] See the January and March 2014 FOMC minutes for a summary of the Committee's discussion.

needed, or that the use of RRPs or term deposits by the Federal Reserve would be at the same cost as IOER.[21] FOMC communications suggest that policymakers are considering the use of these reserve-draining tools during normalization. And, it is possible that some of the operations will involve transactions with terms longer than overnight, which would most likely be at a rate that is above the federal funds rate. A priori, we have little information to gauge the likely cost of these tools. The cost will depend on the rate as well as the quantity of reserves that shift to these alternative tools. To provide a rough gauge as to how costly these tools could be, we assess the effects on Federal Reserve net income if the interest expense is 50 basis points higher than the projected level of the federal funds rate and apply this to all reserve balances. Fifty basis points is roughly one standard deviation of the historical spread between the federal funds rate and the yield on the three-month Treasury bill; assuming all reserve balances are drained to the higher expense tools provides an upper bound on this expense. Although interest expenses rise, there is only a modest effect on the Federal Reserve's cumulative remittances.

The analysis assumes that interest rates follow the median paths forecasted by the primary dealers and Blue Chip respondents. To explore the interest rate sensitivity of our results, we also consider a case where interest rates are 200 basis points higher after liftoff, for both the baseline and MBS sales scenarios. These results provide a rough notion of the interest rate risk embedded in the SOMA portfolio. Compared with the baseline, the higher interest rate path implies greater interest expense on reserve balances, lower net income, and consequently lower remittances to the Treasury. With no MBS sales, we find remittances to the Treasury are halted for three years. In the case of MBS sales, remittances are halted for eight years. Of course, if sales were being implemented and rates rose dramatically as suggested here, policymakers could slow the pace of sales or stop them entirely. In fact, if rates rose, sales, which would put upward pressure on rates, might not be the preferred policy. In addition, the FOMC has said sales are not part of the normalization plan. Finally,

[21] The Federal Reserve has been testing overnight RRP operations since late 2013. Since this tool is overnight, it most likely has a similar expense to IOER and is not discussed here.

in thinking about this scenario, it is important to put the shock in some perspective. Christensen, Lopez, and Rudebusch (2013) report that this interest rate shock scenario is very unlikely.

The sections that follow explore these conclusions in more detail.

3.2 Interest Rate Assumptions

To evaluate the current and future value of the SOMA portfolio, to project the future interest expense of reserve balances, and to project the future interest income from the portfolio, assumptions must be made about the path of interest rates over the projection period. For this analysis, we rely on the consensus near-term interest rate forecasts from the February 2014 Blue Chip survey combined with the consensus long-term Blue Chip forecasts from the December 2013 Blue Chip survey. The assumed path for the federal funds rate and the yield on the ten-year Treasury note are shown in figure 7. The federal funds rate remains in the 0 to 1/4 percent range through the first quarter of 2015, then lifts off during the second quarter. We combine the Blue Chip forecast for the federal funds rate with their forecasts for the five-year, ten-year, and thirty-year Treasuries to construct an entire yield curve.[22]

3.3 Near-Term Balance Sheet Assumptions

This sub-section reviews our projection methodology for selected asset and liability items that are of particular interest.

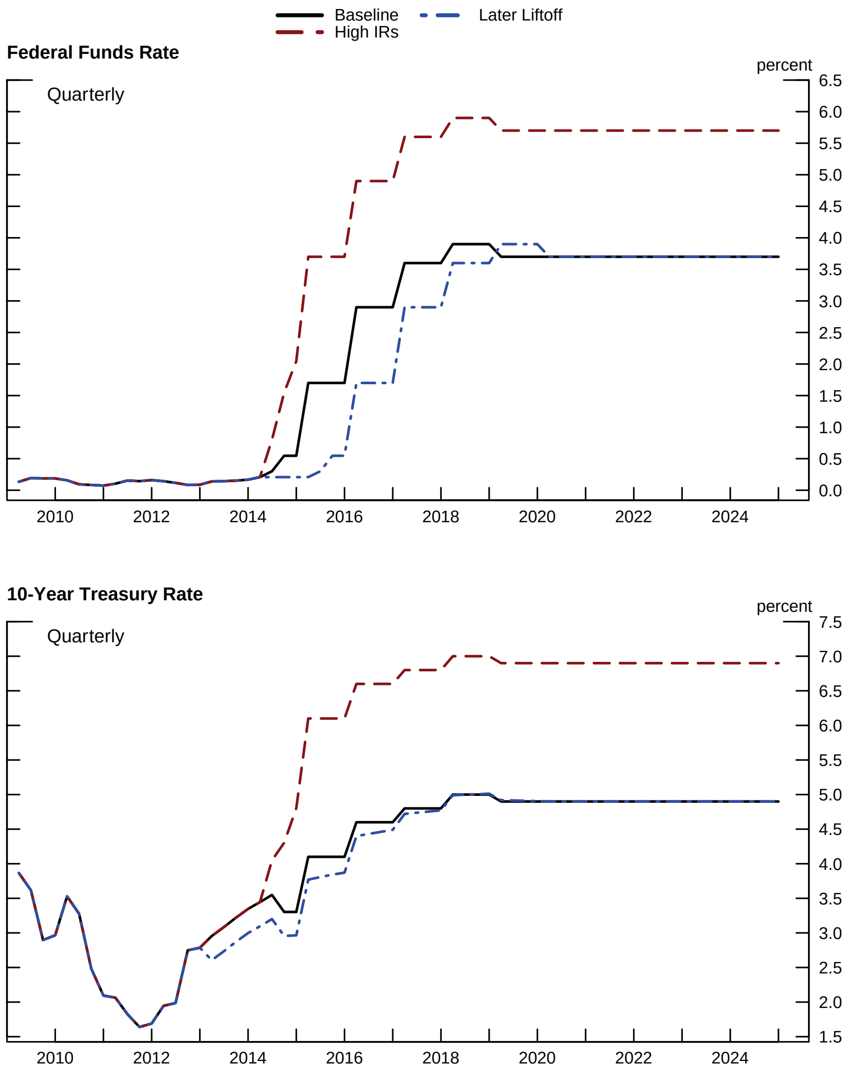
3.3.1 SOMA Portfolio

The evolution of the SOMA portfolio is intended to be consistent with FOMC communications through April 2014. In particular, we assume the following:

(i) Holdings of securities are increased at a declining pace consistent with the February 2014 primary dealer survey, until purchases stop in October 2014. The total expansion in holdings of Treasury securities and MBS over 2013 and 2014 is about $1.5 trillion.

[22] Refer to Carpenter et al. (2013).

Figure 7. Interest Rates



(ii) Reinvestment of principal payments from agency securities into agency MBS continues until the FOMC begins to unwind the current accommodative monetary policy stance.

Specifically, maturing or prepaying securities are assumed to be reinvested until six months prior to the first projected increase in the federal funds rate.

Given the initial composition of the SOMA portfolio on February 28, 2014, the portfolio evolves reflecting these two primary assumptions and the fact that, over time, securities held in the portfolio age, mature, or prepay. The interest earned on securities already in the portfolio is known. The interest rates on securities purchased in the future are based on a projection of all outstanding securities available to purchase including future issuance. Moreover, the composition of future purchases imposes the assumed constraint announced by the Federal Reserve Bank of New York that SOMA holdings in any one CUSIP will remain below 70 percent of the total amount outstanding in that CUSIP.[23]

In contrast to the Treasury securities held in the SOMA, the maturities of the MBS securities held in the portfolio are a function of prevailing interest rates given the embedded optionality of the mortgages underlying these securities. To capture the effect of interest rates on the paydown path of the MBS portfolio, we implement a stripped-down version of the MBS prepayment model proposed in Richard and Roll (1989). We abstract from the seasonality of prepayments, since our primary focus is not on the month-to-month variation of prepayments but rather the long-term prepayment behavior of the portfolio. We also abstract from the "burnout" of prepayments; "burnout" refers to the exhaustion of mortgage refinancings in the MBS, as the loans that remain in the security after a sustained period of refinancing opportunities are unlikely to prepay. Since the rates in our set of scenarios are never decreasing, the underlying mortgages will always be at or moving away from the "money" and will therefore never experience burnout. The remaining terms of the model are a seasoning factor and a refinancing incentive factor. Seasoning captures the observed "ramp" in prepayment behavior. The "ramp" captures the fact that individuals are unlikely to prepay mortgages that were recently issued regardless of the mortgages' "moneyness." The refinancing incentive factor captures the optionality component of the underlying mortgages and is defined as a

[23]Refer to http://www.newyorkfed.org/markets/lttreas_faq.html.

function of the ratio of the coupon rate on the MBS to the prevailing mortgage rate. The refinance incentive factor takes the following form:

$$\begin{aligned} \textit{Refinancing Incentive} &= .2406 - .1389 \\ &\quad * \arctan\left(5.952 * \left(1.089 - \frac{CouponRate}{MortgageRate}\right)\right). \end{aligned}$$

The parameters of this equation are taken from the Office of Thrift Supervision (2000). Using the combined seasoning and refinancing incentive factors, along with our interest rate paths, we can project the cash flows on both current and future MBS holdings, and use these cash flows to obtain the level and approximate value of the MBS portfolio in any given period.[24]

It is important to note that Federal Reserve accounting records the securities holdings at face value and records any unamortized premium as a separate asset or unamortized discount as a separate negative asset. Consequently, we project both the face value of the portfolio and the associated premiums. To project premiums on securities purchased in the future, we calculate the market value of the securities at the time of the purchase, which we assume is the present discounted cash flow of these securities. To discount the cash flows from Treasury securities, we use the yield curves constructed from the Blue Chip forecasts for the federal funds rate, five-year rate, ten-year rate, and thirty-year rate. To discount the cash flows from the MBS securities, we apply an additional add factor to all points along the Treasury yield curve. To calibrate this add factor, we match the realized market value of the MBS held in the portfolio at the end of February to the value of projected cash flows discounted by the Treasury yield curve plus the add factor. For the projection, we take this add factor and phase it into the long-run historical spread of approximately 40 basis points over the next six months.

[24]Given that this methodology only incorporates a single path of interest rates and therefore a single path of cash flows for a given scenario, the valuation neglects the probability of future "moneyness" of the underlying mortgage and is therefore a simplification of a true MBS valuation.

3.3.2 Liabilities and Capital

In our modeling, projections of Reserve Bank liabilities and capital are also critical. In the near term, the size of the balance sheet is driven primarily by securities purchases boosting the asset side of the balance sheet and reserve balances increasing on the liabilities side as the primary offsetting accounting entry. Later in the projection, normalization of the size of the balance sheet occurs, which is the point when the liabilities side begins to determine the size of the balance sheet. That is, like historical times, reserve balances become fairly small, so increases in currency are the main determinant of changes in the size of the balance sheet. For simplicity, we assume that Federal Reserve notes grow in line with the Blue Chip forecast for nominal GDP.[25] Capital paid in is assumed to grow at its decade average of 15 percent per year, and surplus is equated to capital paid in.[26] This growth rate plays a role in the long-run trend growth rate of the SOMA portfolio.

Until the size of the balance sheet is normalized, we allow reserve balances to be endogenous, calculated as the residual of assets less other liabilities less capital. When reserve balances fall to the nominal level of $25 billion as the portfolio shrinks, however, we assume that the Federal Reserve does not allow them to fall further. As currency and Reserve Bank capital are still expanding at that point, purchases of Treasury securities are assumed to restart. Holdings of Treasury securities expand at the same rate as currency and Reserve Bank capital, keeping reserve balances at the assumed $25 billion

[25]In a classic money demand model with no change in velocity, one can proxy money growth with nominal GDP growth. That said, there are a number of factors that influence demand for currency beyond nominal GDP, including demand for currency from abroad, demand for currency during financial crises, and technological change in payment systems.

[26]In the years prior to the financial crisis, capital paid in grew rapidly. Each member bank of the Federal Reserve System is required, by law, to subscribe to shares of its local Reserve Bank in an amount equal to 6 percent of its own capital and surplus. Of this 6 percent, half is held at the Federal Reserve and the other half is on call at the bank. Consolidation in the banking industry, which resulted in rapid growth of member bank assets, and regulatory pressures led to higher key performance indicators from member banks. Member bank asset growth declined during the financial crisis; however, capital-paid-in growth may increase going forward because of, for instance, systemically important financial institution surcharges or Basel III requirements.

level. To maintain reserve balances at $25 billion, we assume that the Desk begins to purchase Treasury bills. Purchases of bills continue until these securities comprise one-third of the Federal Reserve's total Treasury security holdings—about the average proportion of Treasury holdings prior to the crisis. Once this proportion of bills is reached, we assume that the Desk buys coupon securities in addition to bills to maintain an approximate composition of the portfolio of one-third bills and two-thirds coupon securities.

3.4 Exit Strategy Assumptions for the Balance Sheet

We tie our modeling of the normalization of policy to the forecasted initial increase in the federal funds rate. We rely on the general principles for the exit strategy that the FOMC outlined in the minutes of the June 2011 FOMC meeting, updated for discussion in the June 2013 minutes. Specifically, we assume that the reinvestment of securities ends six months before the federal funds lifts off from the zero lower bound. Although the FOMC guidelines note that reserve-draining tools will be used prior to raising the funds rate, to support the implementation of an increase in the federal funds rate when appropriate, we abstract from this detail in the baseline projection. The key assumptions used in the baseline and alternative normalization projections are summarized in table 6 in the appendix.

4. Baseline

With the assumptions in place, this section presents the baseline balance sheet and income projections, assuming no MBS sales. This scenario illustrates one path for monetary policy normalization that is generally consistent with current FOMC communications. Critical assumptions for this scenario, as well as all other scenarios, are found in table 6 in the appendix.

4.1 Balance Sheet

Figure 8 presents the projections of key balance sheet line items (the solid lines). As shown in the top-left panel, SOMA holdings move

Figure 8. Selected Assets and Liabilities of the Balance Sheet

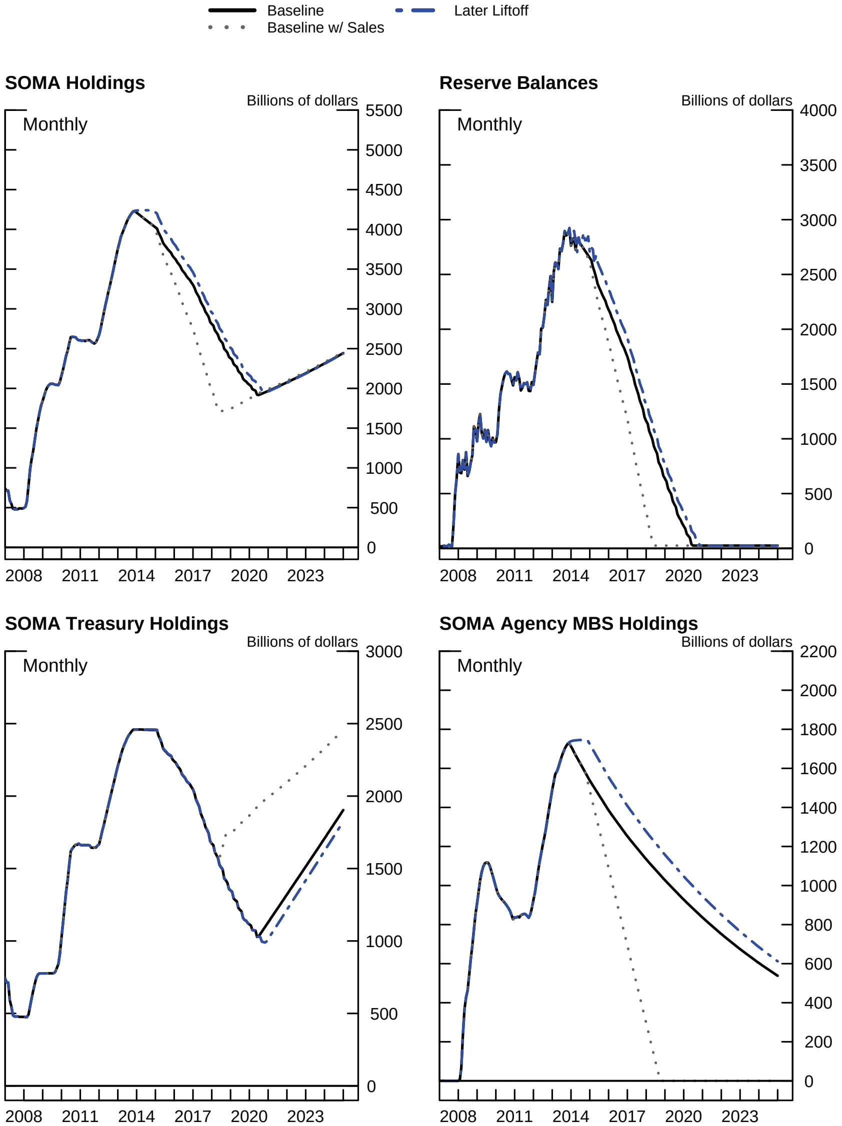


Table 4. Projected Maturing Treasury Securities, $Billion

2015	$3.5
2016	$215.5
2017	$194.2
2018	$374.0

up slightly through the middle of 2014, reflecting the continuation of the asset purchase program. After the conclusion of purchases in October 2014, the baseline portfolio begins to decline from its peak level of $4.2 trillion as securities are allowed to redeem without reinvestment. The peak size of the portfolio is much larger than the size of SOMA immediately prior to the financial crisis, which was roughly $800 billion, and roughly $3 trillion above Federal Reserve notes.

After purchases end, under the assumption that the FOMC begins to allow all asset holdings to roll off the portfolio as the first step in the exit strategy, SOMA holdings begin to decline. However, because the Federal Reserve sold or redeemed almost all of the Treasury securities with less than three years of remaining maturity during the maturity extension program in 2011–12, the portfolio holds very few shorter-dated Treasury securities at the time redemptions begin. Therefore, as shown in the bottom-left panel, when rolloff begins in November 2014, only a minimal amount of securities are maturing, and Treasury securities do not immediately decline. As shown in table 4, the amount of Treasury securities that are maturing becomes sizable in 2016. In particular, between 2016 and 2018, nearly $750 billion in Treasury securities are expected to mature and roll off the portfolio.

While Treasury securities do not decline until sometime after liftoff, MBS holdings, the bottom-right panel, begin to contract immediately. These holdings decline modestly, as prepayments are projected to be about $45 billion per quarter around the time of liftoff, and then slow further as rates rise. By the end of 2025, MBS holdings are roughly $540 billion. Recall that in former Chairman Bernanke's press conference he noted, "in the longer run, limited sales could be used to reduce or eliminate residual MBS holdings."

This projection suggests that residual holdings are still a sizable amount.

The decline in Treasury and MBS securities implies that the size of the balance sheet is normalized in May 2021 with $1 trillion in Treasury securities holdings and $890 billion in MBS holdings. Afterwards, SOMA begins to expand in line with the growth of currency and capital. Purchases of Treasury securities can be strategic to move the portfolio toward the composition that the FOMC desires in the longer run.

The level of reserve balances throughout the projection roughly reflects the asset program minus currency in circulation. As shown in the top-right panel, reserve balances top out at $2.9 trillion in November 2014, as the SOMA portfolio peaks with the end of asset purchases. Further out in the projection, the reduction in the size of the SOMA portfolio, along with the projected growth of Reserve Bank capital and Federal Reserve notes, results in declines in the level of reserve balances. Since we assume that reserve balances do not fall below $25 billion, by mid-2021 the Desk again starts to reinvest maturing Treasury securities and begins purchases of Treasury securities. If one were to consider a higher level of steady-state reserve balances, then normalization would occur slightly earlier.

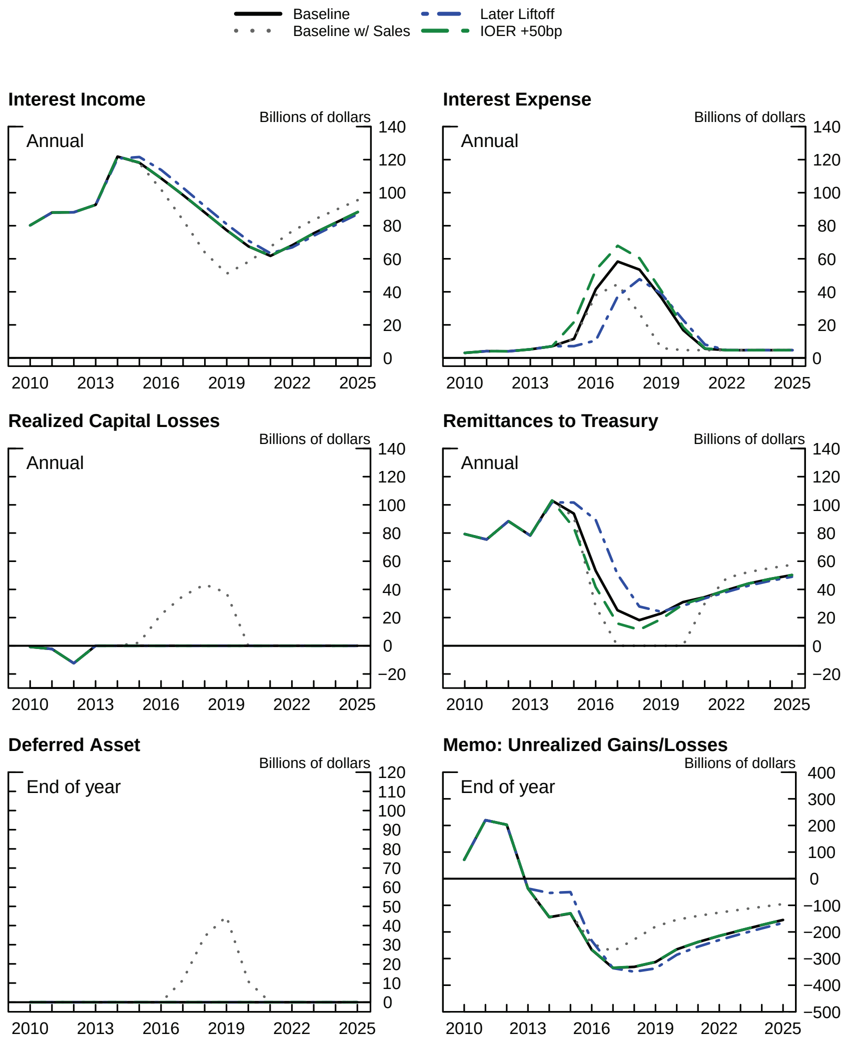
4.2 Income

Figure 9 shows the path of Reserve Bank net income. Because of the large size of the SOMA portfolio, combined with the (relatively high) coupons on the securities, interest income is elevated for some time.[27] As the SOMA portfolio begins to contract with the assumed steps in the exit strategy, interest income declines through mid-2021. After reserve balances reach $25 billion, Treasury purchases resume, expanding the portfolio, causing interest income to rise.

Interest expense reflects both the level of the federal funds rate and the level of reserve balances. The federal funds rate in the dealer

[27]The current weighted average coupon on the SOMA portfolio is 3.4 percent. This weighted average coupon evolves over the projection period as securities are purchased or are removed from the portfolio.

Figure 9. Income Projections



survey begins to rise in 2015, and interest expense rises with it. However, in 2018, interest expense begins to moderate, as the decline in reserve balances more than offsets the rise in the federal funds rate.

On net, annual remittances to the Treasury remain elevated by historical standards in the near term, but then decline. The trough in remittances is $18 billion in 2018, a level that is not much lower than the $25 billion average remittances in the decade prior to the financial crisis. There is no deferred asset in this baseline projection. Cumulative remittances from 2009 through 2025 are $918 billion, above the level predicted by a trend growth in remittances. Of course, the overall effect on the federal government's finances is more complicated than just the impact from Federal Reserve remittances. For example, if asset purchases provide meaningful economic stimulus, the increase in government revenues from faster economic growth could more than offset any lull in remittances. Further, if the asset purchases lower interest rates, the interest expense of the federal government is lower.

Although only realized gains or losses affect the Federal Reserve's income, we project the unrealized gain or loss on the portfolio. The unrealized loss on the portfolio at a point in time is defined as the difference between the projected market value of the portfolio, less the amortized cost of the portfolio (par value of the securities plus net premiums). Given the large SOMA portfolio and the projected rise in interest rates, under the baseline projections, the portfolio is in an unrealized loss position at the end of 2014. This unrealized loss position continues to grow through the beginning of 2018, but subsequently diminishes as the portfolio shrinks through redemptions and sales.

5. Alternative Normalization Strategies

The baseline assumption of how the FOMC may choose to unwind unconventional monetary policy is one of many alternatives available to the Committee. Here we consider a few alternative normalization strategies: MBS sales, alternative forward guidance, and term-draining tools. We compare the effects of these alternative strategies on the balance sheet and income relative to the baseline projection.

5.1 MBS Sales

The June 2011 FOMC minutes laid out exit strategy principles that included selling MBS over a period of three to five years at some date after the funds rate moved above the zero lower bound.

Selling securities is one way of raising interest rates; see, for example, Ihrig et al. (2012). In addition, FOMC members have expressed a desire to remove MBS from the portfolio, in part reflecting their view that the Federal Reserve should minimize the extent to which the Federal Reserve portfolio might affect the allocation of credit across sectors of the economy.[28] In this projection, we consider selling MBS holdings over four years, commencing six months after liftoff. Selling MBS after the funds rate starts to rise is not only a way to remove MBS from the portfolio but also a way to reduce the amount of unconventional monetary policy in place at a time when the FOMC wants to firm monetary policy. A consequence of selling MBS is that the Federal Reserve will realize capital loses, reflecting selling relatively low-coupon MBS in an environment with rising interest rates. This type of strategy will reduce remittances to the Treasury.

The implications of MBS sales on the balance sheet are shown in figure 8. With MBS sales (the dashed lines), MBS holdings drop much faster than in the baseline. Consequently, the balance sheet with MBS sales normalizes in size around May 2019, implying that unconventional monetary policy is unwound one year earlier than in the baseline.

The income projection is a bit different from the baseline. Because of MBS sales, as shown in figure 9, there are fewer securities in SOMA and so interest income is lower in the medium term. Interest expense is also lower, because of the reduction in reserve balances. Under this path of interest rates, with sales come realized capital losses.[29] Over the four-year sales period, September 2015 to August 2019, these losses average roughly $35 billion per year. Putting the pieces together, remittances fall to zero from 2017 through 2020.

The projection has a deferred asset that peaks at about $45 billion. This illustrates that if policymakers choose to sell MBS, there is a chance that remittances will be zero for a period of time. Moreover, as Greenlaw et al. (2013) have suggested, this could involve

[28] Refer to the minutes of the April 2011 FOMC meeting, available at http://www.federalreserve.gov/monetarypolicy/fomcminutes20110427.htm.

[29] Treasury securities sales conducted under the maturity extension program resulted in small gains because of the low level of market interest rates in 2012 and the relatively higher coupon on the securities sold.

negative political pressure. However, zero remittances do not mean the Federal Reserve cannot conduct monetary policy. Other central banks have operated with losses. For example, the Swiss National Bank experienced an operating loss in 2008 and 2010, as a result of their currency interventions in support of the Swiss franc.[30] Despite these losses, the ability of the Swiss National Bank to influence monetary conditions was relatively unaffected. Moreover, policymakers have suggested this is not their preferred normalization strategy and would have the choice to slow or stop sales if this policy was found to be inconsistent with their dual mandate.

Despite the limited period of zero remittances, the level of remittances plus capital remains positive for most of that time, suggesting that the Federal Reserve could see only brief periods of negative equity. In addition, from an operational point of view, zero remittances do not preclude the FOMC from conducting monetary policy. As noted by Cukierman (2011) and others, a central bank differs from a private corporation in that its objective is not profit maximization—for example, in the United States, the Federal Reserve's objective is promoting maximum employment, stable prices, and moderate long-term interest rates—and it can therefore operate with negative equity.

For simplicity, this scenario is modeled assuming the same underlying macroeconomy as in the baseline. Of course, the underlying economy could differ, and most likely would be part of the reason that the FOMC chose to deviate from its current plans not to sell MBS in its normalization strategy. For example, it might be the case that the economy starts to expand at a faster rate than desired or inflation rises above the Committee's 2 percent objective. If so, MBS sales could put upward pressure on interest rates and return the economy to the baseline path. So, assuming that the monetary policy actions are effective, the medium- to longer-run projection for the economy should be similar to what is assumed in the baseline.

[30] Refer to "Annual Result of the Swiss National Bank" for 2008 and 2010, available for download at http://www.snb.ch/en/mmr/reference/pre_20090304/source/pre_20090304.en.pdf and http://www.snb.ch/en/mmr/reference/pre_20110303/source/pre_20110303.en.pdf.

5.2 Alternative Forward Guidance Thresholds

From December 2012 to March 2014, the FOMC provided forward guidance about the federal funds rate in terms of a threshold for the unemployment rate. The FOMC statement explicitly noted that the funds rate would remain in "this exceptionally low range . . . at least as long as the unemployment rate remains above 6-1/2 percent." In the January 2014 FOMC minutes, the Committee contemplated alternative quantitative forward guidance.[31] In March, the minutes noted that a "participant favored introducing new quantitative thresholds of 5½ percent for the unemployment rate and 2¼ percent for projected inflation." Here, we consider the impact of implementing a threshold that would push out liftoff from the date assumed in the baseline.

Lowering the threshold implies shifting market participants' beliefs to a later liftoff of the federal funds rate. For illustrative purposes, we assume the liftoff occurs four quarters later than the baseline, which is when the Blue Chip forecast has the unemployment rate reach 5.6 percent and CPI inflation one year out is 2.3 percent. This later liftoff implies that the contour of the balance sheet will change, delaying the decline in the portfolio and therefore the normalization of the size of the balance sheet. In addition, the delay in liftoff affects income. Of course, a critical question is how fast rates will rise after liftoff. We assume the funds rate moves up at the same pace as the baseline scenario, as illustrated in figure 7. We also assume that rolloff begins six months before liftoff, delaying the start to rolloff by six quarters from the baseline. The ten-year yield is adjusted by a simple approximation of the expected change in the rate as implied by the expectations hypothesis. That is, we lower the ten-year yield by the average decrease in the path of the federal funds rate over the next forty quarters.

Figure 8 illustrates the evolution of the balance sheet (the dashed-dotted lines). The delayed start to stopping reinvestment implies larger MBS holdings throughout the projection period, with about $600 billion in holdings at end-2025.[32] For Treasury securities, however, the delayed start to allowing the securities to roll off the

[31] FOMC minutes are found here: http://www.federalreserve.gov/monetarypolicy/fomccalen

[32] Chairman Bernanke mentioned in his press conference statement that residual agency MBS holdings could be sold at some point in the future.

portfolio when they mature is not as dramatic. This is in part a result of the maturity extension program, in which the Federal Reserve sold or allowed to redeem all securities with remaining maturity of less than three years and purchased the same amount of securities with remaining maturity of six years or greater over the course of 2011 and 2013. Consequently, there are few securities maturing in 2015 (see table 4). Hence, projected Treasury holdings in the medium term are not that different from the baseline. Of course, later in the period, Treasury holdings are less than the baseline since there are more MBS holdings in this scenario. Taken together, the evolution of the securities holdings implies that normalization of the size of the balance sheet is delayed by six months relative to the baseline, implying a longer period for unconventional monetary policy to be in place.

Figure 9 shows that this policy would boost remittances to the Treasury by a sizable amount. Interest income is boosted through the medium run by the higher securities holdings. Interest expense is generally lower than the baseline, reflecting the fact that delayed start to the rise in the federal funds rate allows more Treasury securities to roll off the books and reduce reserve balances faster once the federal funds rate rises. These two factors imply that remittances are much higher through the medium term, with a trough of roughly \$25 billion. Cumulative remittances are \$989 billion, \$71 billion more than the baseline. This scenario shows that if the FOMC chose to lower the threshold, for whatever reason, unconventional monetary policy would be unwound a bit more slowly, while remittances would be boosted relative to the baseline scenario. Again, MBS holdings would be sizable at the end of 2025.

Of note, our analysis abstracts from possible macroeconomic effects of delaying the rise in rates. For example, while there could be beneficial effects on output if rates were held “low for long,” inflation could rise substantially. In particular, evidence from DSGE models suggests a particularly outsized response from forward guidance, and some authors suggest methodologies for damping this response (Del Negro, Giannoni, and Patterson 2013). Moreover, there could be evidence of excess risk taking in financial markets, leading to financial instabilities, discussed in Feroli et al. (2014). The conditionality of forward guidance should mitigate these risks; however, as with any policy decision, there exists some uncertainty and therefore some risk of an unfavorable outcome.

5.3 Term Reserve-Draining Tools

So far, our analysis has assumed that the Federal Reserve has not engaged in any active liability management and, as a result, reserve balances passively decline as securities mature and roll off the portfolio. As noted in the June 2011 exit principles, the Committee may elect to incorporate liability management tools to reduce or "drain" reserve balances into its exit strategy in order to support conditions in which the federal funds rate trades near the intended target policy rate. Tools that could be used to drain reserve balances include reverse repurchase agreements and term deposits. RRPs can be conducted at an overnight or term frequency. Overnight RRPs would result in the balance sheet composition shifting from reserve balances to RRPs, but with the overnight rate likely being near IOER, there would likely be only a minimal effect on income. For term-draining tools, however, the income effect could be more noticeable.

If the Federal Reserve were to use term-draining operations where counterparties demanded a relatively high rate of return since these term operations have a longer maturity and would be less liquid than reserve balances, interest expense would rise. To illustrate this point, we assume that *all* reserve balances pay 50 basis points above IOER. This scenario is calibrated to one standard deviation of the historical spread between the federal funds rate and selected one- and three-month money-market rates.

The size of the balance sheet is unchanged in this scenario, though there would be a shift in the composition of liabilities: reserve balances would fall 1:1 with the use of term deposits and term RRPs. Interest expense would rise, with an increase of 50 basis points per each dollar drained. Given we assume all reserve balances are drained, an extreme example, as shown in table 5 and figure 9, even in this case, annual remittances are only marginally affected. This result is because the balance sheet is shrinking at the time interest expense is rising. The impact of higher costs reduces cumulative remittances by about $40 billion. Given the magnitude of the other

Table 5. Projected Remittances, $Billion

	2015	2016	2017	2018	2019	2020	Cumulative 2009–2025
Baseline	93.8	53.3	25.2	18.2	22.9	31.0	918.4
Costly Draining*	83.8	41.7	15.8	11.4	18.9	29.3	875.1

*Term-draining tools implemented on all reserve balances from liftoff to when reserve balances are normalized.

costs and revenues, the expense associated with draining tools does not seem too large.

6. Interest Rate Sensitivity—Deferred Asset

Above we found that with baseline assumptions the Federal Reserve will normalize monetary policy and its balance sheet without any deferred asset. The only way that remittances could fall to zero in this case would be if interest expense rose sustainably while reserve balances were elevated. In the MBS sales scenario, remittances could be halted for a longer period than projected above if realized losses were larger. To illustrate these points, we allow interest rates to rise 200 basis points higher after liftoff than in the baseline projection. The results will highlight the point discussed in the December 2012 minutes: "Depending on the path for the balance sheet and interest rates, the Federal Reserve's net income and its remittances to the Treasury could be significantly affected during the period of policy normalization." In particular, it could be necessary to raise rates faster than in the baseline if the economy was overheating or if inflation was consistently well above the Committee's 2 percent objective. This shock to interest rates has two effects on the size of the balance sheet. First, higher interest rates reduce the incentive for mortgage holders to refinance, causing MBS prepayments to slow. Second, higher interest rates increase interest expense on reserve balances in both scenarios and realized losses in the scenario with sales. All these factors increase the likelihood of a deferred asset, which also delays the date of normalization.

Figure 7 shows the projected rates for the higher interest rate scenarios. The federal funds rate and ten-year Treasury yield rise at a faster pace at liftoff, and after one year are 200 basis points higher than the baseline rates over the remainder of the projection. In the baseline interest rate projection, the ten-year Treasury yield rises by approximately 1 percentage point between end-2014 and end-2016. By contrast, the 200-basis-point shock implies that the ten-year Treasury yield is increasing by 3 percentage points over those two years.

There are a couple of ways to put the size of this shock in perspective. To start, this size shock is 1.3 percentage points above the average forecast of the top 10 highest respondents in the December 2013 Blue Chip survey (roughly 20 percent of the sample), and thus is probably comfortably above most market participants' interest rate projections. In addition, for a historical comparison, from 1978 to present, the standard deviation of the two-year change in the ten-year Treasury yield is 1.6 percentage points. As a result, this higher interest rate scenario should be seen as a somewhat unlikely scenario, but not an implausible one. Of course, to the extent that inflation expectations have become better anchored through time, this increase in interest rates may be even less probable than the historical record may suggest.

Focusing on the baseline, no-MBS-sales scenario, shown in figure 10, the interest rate shock does not substantially change the Federal Reserve's balance sheet projections.[33] The income projection, as shown in figure 11, does change, however. The higher federal funds rate implies greater interest expense. Once combined with non-interest income and expenses, remittances to the Treasury fall to zero for several years and a deferred asset is booked for 2017 through 2020.

How should we interpret this shock? Cumulative remittances from 2009 to 2025 are $791 billion, about $125 billion less than in the baseline. To put some perspective on this value, it remains greater than what would be suggested by a pre-crisis 1990–2007 trend level of remittances. This projection is also similar to what Christensen, Lopez, and Rudebusch (2013) report as their

[33] A deferred asset will have a small impact on the size of the SOMA portfolio, but not enough to see in the figures.

Figure 10. Selected Assets and Liabilities of the Balance Sheet

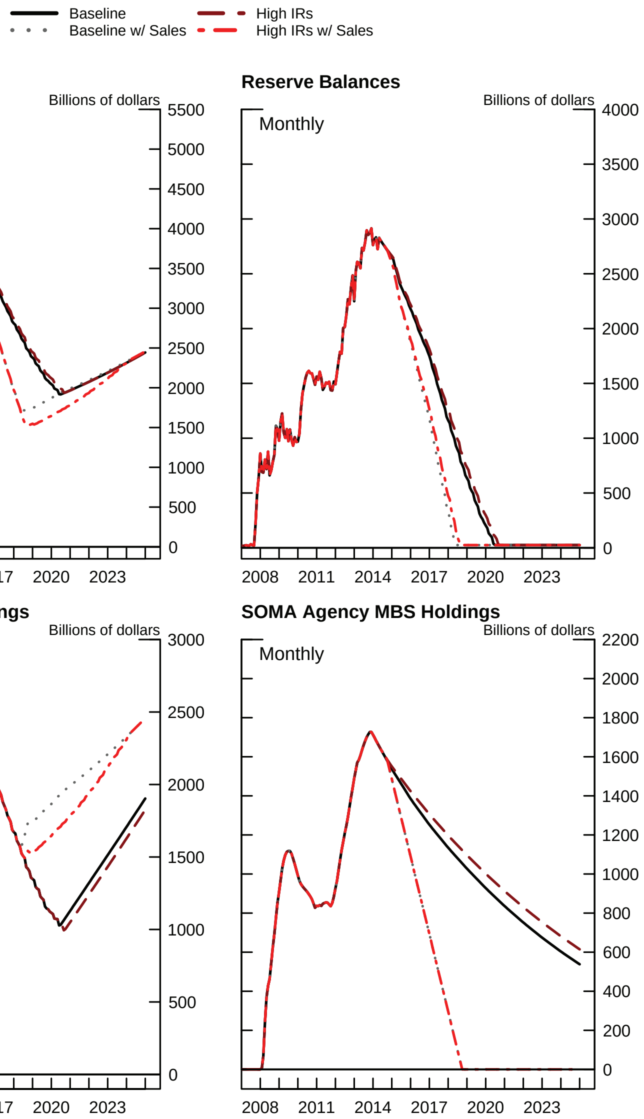
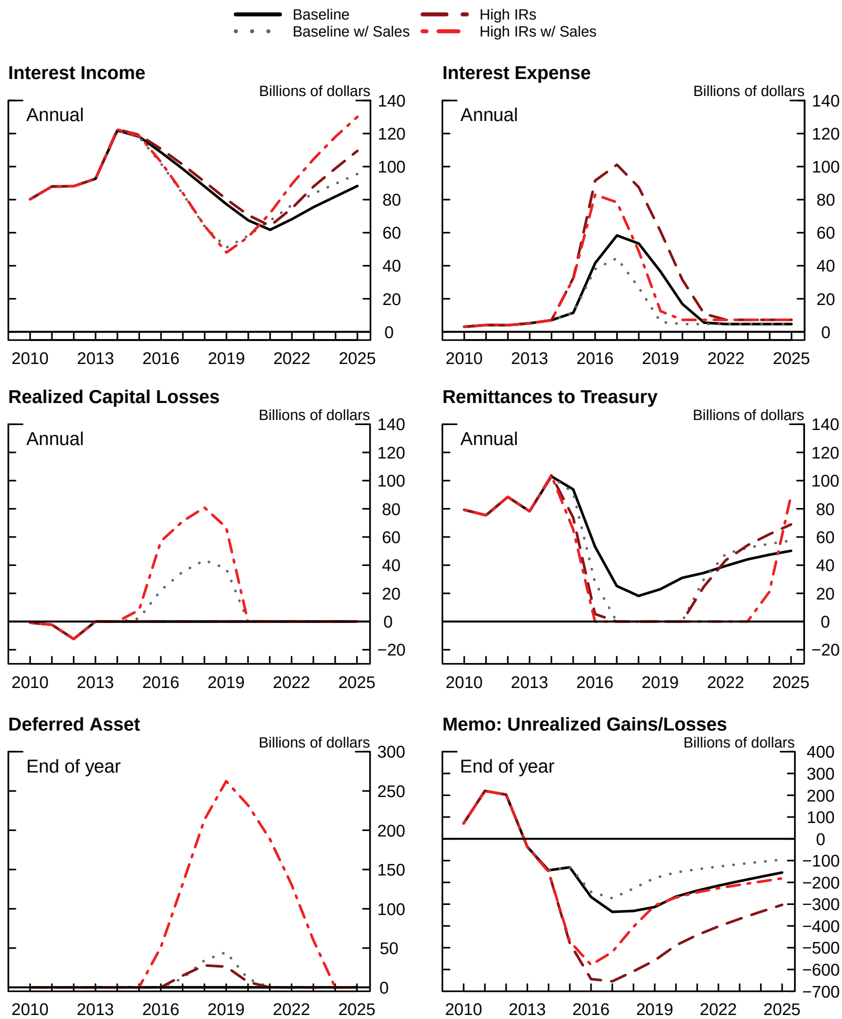


Figure 11. Income Projections



lower-bound "probability-based" stress scenario.[34] Further, they note that the chance that cumulative remittances would be below an underlying trend value is less than 0.1 percent.

[34] Christensen, Lopez, and Rudebusch (2013) suggest that the probability of this shock is less than 5 percent.

Turning to a scenario where MBS are sold, the higher interest rate path does not change the balance sheet by much, but with higher interest expense and larger capital losses, a deferred asset peaks at nearly $263 billion. Moreover, remittances to the Treasury are halted for 8³/4 years. Cumulative remittances from 2009 to 2025 are $635 billion, about $283 billion less than in the baseline. Of course, the June 2013 minutes stated that policymakers do not expect to sell agency mortgage-backed securities during the process of normalizing monetary policy. Therefore, this scenario is very unlikely to play out. In addition, policymakers could change their exit strategy, slowing or stopping these asset sales.

These sensitivity scenarios illustrate that in some circumstances the Federal Reserve could have years with no remittances to the Treasury and a deferred asset on its books. It is important, however, that these scenarios be viewed within a macroeconomic framework. As noted above, to the extent that asset purchases are effective in stimulating the economy, overall government revenues would be boosted on net, despite the capital losses at the Federal Reserve. In addition, one should consider the Federal Reserve's remittances over the entire period of unconventional monetary policy. Overall, average annual remittances to the Treasury even in these shock scenarios remain well above the average annual remittances of $25 billion recorded prior to the crisis.

More broadly, as mentioned above, zero remittances would not affect the conduct or stance of monetary policy. This assertion is based on a number of points that have been raised previously in the academic literature. First, monetary policy in the United States has historically been conducted by adjusting short-term interest rates, and there is no direct, causal link between the remittances to the Treasury and short-term interest rates.

Second, Cukierman (2011) and others cite that the main drivers of central bank insolvency include assumptions of problem assets by the central bank, fiscal abuse, and a buildup of large stocks of foreign reserves, sometimes to support an exchange rate peg. These drivers are absent from the U.S. case. Other drivers that could be more applicable to the United States are a need to absorb banking-sector excess liquidity and central bank purchases of relatively low-yielding instruments. That said, in most scenarios, we find that any deferred asset would most likely be for a handful of years and would not present an ongoing concern.

And third, one possible (though in our view, unlikely) channel through which losses could impair monetary policy is if, for some reason, economic agents believed that the central bank's earnings affected inflation. If beliefs were formed in that way, perhaps because of a misunderstanding of the mechanics of the economy, inflation expectations could rise and thereby become embedded in actual inflation. Relatedly, a model by Hall and Reis (2013) provides a theoretical model that explores the potential for a central bank to pursue an inflationary policy in order to erode capital losses. They state that the realization of this outcome in the United States is unlikely and find the potential for the Federal Reserve to become insolvent to be "remote." By contrast, empirical evidence provided by Klueh and Stella (2008) shows that in some countries, there can be a negative relationship between inflation and central bank capital. Their results were based on a set of countries where central bank losses as a percent of nominal GDP approached 2 percent, well below any levels projected here.

Such a process of a feedback loop of inflation and losses seems unlikely for the case of the United States. In particular, authors such as Del Negro and Sims (2014) point to the importance of the present value of net worth, rather than of equity, as the key measure of central bank solvency, and perhaps by extension, central bank independence. Because the Federal Reserve has an expected (positive) stream of seigniorage revenue from its currency franchise, the potential impact of a short-lived deferred asset on inflation expectations or on the necessity of the central bank to be recapitalized by the Treasury should be non-existent, or negligible. That said, Del Negro and Sims do highlight extraordinary circumstances of alternative equilibria under which the presented discounted value of seigniorage revenue is not sufficient to cover the gap between the interest earned on assets less the interest paid on liabilities. This could be a result of inflation expectations becoming embedded in asset values, thereby eroding their present worth. In their model, a central bank would have to resort to fulfilling those expectations by allowing inflation to drift above its target. However, in order for this to occur, the balance sheet would likely have to be multiples of the size of the current balance sheet, an unlikely outcome.

Moreover, given this apparatus to produce income projections for any monetary policy scenario, policymakers could evaluate alternative ways to remove monetary policy accommodation with the idea of choosing the path that most likely reduces the possibility of zero remittances and, hence, political scrutiny of their actions. Two additional strategies not presented here, for example, but that could reduce the probability of zero remittances are security sales in the near term when remittances are robust and committing to a more gradual pace of tightening after liftoff. Looking across all possible strategies, there would be trade-offs between alternative monetary policy actions, their effect on economic activity, and remittances. When considering these alternative actions, the FOMC would need to keep in mind its dual mandate of full employment and price stability.

7. Conclusion

In this paper, we have outlined a variety of ways the FOMC may unwind the unconventional monetary policy that it has instituted over the past several years. The different policies have implications for the length of time unconventional policy is in place, the composition of the Federal Reserve's balance sheet, and remittances to the Treasury. How fast unconventional monetary policy unwinds and the tools used depends on FOMC actions, and we discussed the impact of a few of these possibilities.

Appendix

Table 6. Key Assumptions of the Projections

Assumption	Baseline	Baseline with Sales	Later Liftoff
Current Portfolio Strategy			
Agency Reinvestments	Agency MBS	Agency MBS	Agency MBS
Treasury Purchases			
Total Amount (2013–14)	$790 billion	$790 billion	$790 billion
Jan. 2013 to Dec. 2013	45	45	45
Jan. 2014	40	40	40
Feb. 2014 to Mar. 2014	35	35	35
Apr. 2014	30	30	30
May 2014 to Jun. 2014	25	25	25
Jul. 2014	20	20	20
Aug. 2014 to Sep. 2014	15	15	15
Oct. 2014	10	10	10
MBS Purchases			
Total Amount (2013–14)	$680 billion	$680 billion	$680 billion
Jan. 2013 to Dec. 2013	40	40	40
Jan. 2014	35	35	35
Feb. 2014 to Mar. 2014	30	30	30
Apr. 2014	25	25	25
May 2014 to Jun. 2014	20	20	20
Jul. 2014	15	15	15
Aug. 2014 to Sep. 2014	10	10	10
Oct. 2014	5	5	5
Exit Strategy			
Fed. Funds Liftoff	2015:Q2	2015:Q2	2016:Q2
Redemptions Start	Nov. 2014	Nov. 2014	Nov. 2015
Sales Start	N/A	Oct. 2015	N/A
Sales End	N/A	Sep. 2019	N/A

References

Carpenter, S., J. Ihrig, E. Klee, A. Boote, and D. Quinn. 2013. "The Federal Reserve's Balance Sheet and Earnings: A Primer and Projections." FEDS Paper No. 2013-1 (January), Board of Governors of the Federal Reserve System.

Christensen, J., J. Lopez, and G. Rudebusch. 2013. "A Probability-Based Stress Test of Federal Reserve Assets and Income." Working Paper No. 2013-38 (December), Federal Reserve Bank of San Francisco.

Cukierman, A. 2011. "Central Bank Independence and Monetary Policymaking Institutions — Past, Present and Future." *European Journal of Political Economy* 24 (4): 722–36.

Del Negro, M., M. Giannoni, and C. Patterson. 2013. "The Forward Guidance Puzzle." Staff Report No. 574 (May), Federal Reserve Bank of New York.

Del Negro, M., and C. Sims. 2014. "When Does a Central Bank Require Fiscal Support?" Mimeo (March).

Edwards, C. E. 1997. "Open Market Operations in the 1990s." *Federal Reserve Bulletin* (November): 859–74.

Federal Reserve Bank of New York. 2013. "Domestic Open Market Operations in 2012." Available at http://www.ny.frb.org/markets/omo/omo2012.pdf.

Feroli, M., A. Kashyap, K. Schoenholtz, and H. S. Shin. 2014. "Market Tantrums and Monetary Policy." Chicago Booth Working Paper No. 14-09 (February).

Friewald, N., R. Jankowitsch, and M. G. Subrahmanyam. 2014. "To Disclose or Not to Disclose: Transparency and Liquidity in the Structured Product Market." Mimeo, NYU Stern School of Business (February 15).

Greenlaw, D., J. D. Hamilton, P. Hooper, and F. Mishkin. 2013. "Crunch Time: Fiscal Crises and the Role of Monetary Policy." (February 22).

Hall, R. E., and R. Reis. 2013. "Maintaining Central-Bank Solvency under New-Style Central Banking." Mimeo.

Ihrig, J., E. Klee, C. Li, B. Schulte, and M. Wei. 2012. "Expectations about the Federal Reserve's Balance Sheet and the Term Structure of Interest Rates." FEDS Paper No. 2012-57, Board of Governors of the Federal Reserve System.

Judson, R., and R. Porter. 1996. "The Location of U.S. Currency: How Much Is Abroad?" *Federal Reserve Bulletin* 82 (October): 883–903.

Klueh, U. H., and P. Stella. 2008. "Central Bank Financial Strength and Policy Performance: An Econometric Evaluation." IMF Working Paper No. 08/176.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2011. "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Monetary Policy." *Brookings Papers on Economic Activity* (Fall).

Li, C., and M. Wei. 2013. "Term Structure Modeling with Supply Factors and the Federal Reserve's Large-Scale Asset Purchase Programs." *International Journal of Central Banking* 9 (1): 3–39.

Meltzer, A. 2010. *A History of the Federal Reserve*, Vol. 2, Book 1, 1951-1986. Chicago: University of Chicago Press.

Office of Thrift Supervision. 2000. "Net Portfolio Value Model Manual."

Rudebusch, G. D. 2011. "The Fed's Interest Rate Risk." *Economic Letter* (Federal Reserve Bank of San Francisco) 2011-11 (April 11).

Richard, S. F., and R. Roll. 1989. "Prepayments on Fixed-Rate Mortgage-Backed Securities." *Journal of Portfolio Management* 15 (3): 73–82.

Vickrey, J., and J. Wright. 2013. "TBA Trading and Liquidity in the Agency MBS Market." *Economic Policy Review* (Federal Reserve Bank of New York) 19 (1).

Sovereign Risk, European Crisis-Resolution Policies, and Bond Spreads*

Juha Kilponen, Helinä Laakkonen, and Jouko Vilmunen
Bank of Finland

We study the effects of a wide range of European crisis-resolution policies, including large-scale asset purchase programs of the ECB, on ten-year sovereign bond spreads of seven European countries. Our results based on daily data on bond spreads suggest that policies that are directly geared towards easing the funding strains of the sovereigns and improving market liquidity have been most effective in calming the European sovereign markets. Quantitatively the largest effects on bond spreads are due to announcements of ECB's SMP program and OMTs. At the same time, announcements of financial assistance programs have typically increased somewhat the perceived riskiness of long-term bonds in the guarantor countries but reduced the bond spreads in the countries receiving funding.

JEL Codes: F34, E42, G15.

1. Introduction

European sovereign crises have led to a number of policy initiatives by the European authorities, including the decision to establish the

*This is an updated and revised version of the Bank of Finland Research Discussion Paper No. 22/2012. We would like to thank Falk Bräuning, Juha Junttila, Christophe Kamps, David Mayes, Matti Viren, Tuomas Välimäki, and the conference and seminar participants in the ECB Public Finance Workshop, the Center for European Studies Workshop, Workshop on Sovereign Risk, Fiscal Solvency and Monetary Policy, Workshop on The Macroeconomics of Sovereign Debt, HECER Time Series Econometrics Seminar, and Bank of Finland Research Workshop for constructive comments. The views expressed herein are those of the authors and do not necessarily reflect the views of the Bank of Finland or the European Central Bank System. Author contact: juha.kilponen@bof.fi, helina.laakkonen@bof.fi, jouko.vilmunen@bof.fi.

European Stability Mechanism (ESM) as a follow-up to the European Financial Stability Facility (EFSF) and the European Financial Stability Mechanism. A number of important policy measures have also been directed to enforce commitment to common fiscal rules and improve surveillance power of the union over national budgetary policies in order to improve the fiscal discipline and policy coordination within the euro area.

At the same time, the European Central Bank (ECB) has used a series of non-standard policy measures to contain pressure to the financial system. The ECB has provided both short-term and long-term liquidity support to banks, lowered its main policy rate to historically low levels, and set up large-scale asset purchase programs, like in many other central banks, to revive dysfunctional segments of the capital markets. Enhanced liquidity support has included lengthening of the maximum maturity of refinancing operations, extension of the eligible collateral list, provision of liquidity in foreign currencies, and provision of unlimited liquidity at a fixed rate. The ECB's Covered Bond Purchase Program (CBPP) and Securities Market Program (SMP) were set up to purchase private and public bonds from the markets. The aim of these two programs was to support the functioning of a specific financial market segment that was severely affected by the financial crisis. Speculation over a possible breakup of the European Monetary Union intensified in late 2011 and early 2012, culminating in a "whatever-it-takes" speech by ECB President Mario Draghi in July 2012 and the announcement of the ECB's Outright Monetary Transactions (OMTs) in September of the same year. In contrast to the SMP, OMTs would be without an ex ante quantitative limit but would be conditional on participation in the EFSF/ESM program.

In this paper, we study the impact of these euro-wide policy decisions on the long-term sovereign bond yields of seven euro-area countries: Germany, France, Spain, Italy, Portugal, Greece, and Ireland. We study the policy announcement effects with an empirical model, where the explanatory variable is the change in the spread between the ten-year government bond yield and the ten-year euro swap rate. Our daily data runs from January 1, 2007, to September 30, 2013.

In order to estimate reliably the announcement effect, we control for the effect of credit risk, liquidity risk, and the general risk appetite, as they have been found[1] to be the main risk factors determining the yields of the European sovereign bonds. The policy decisions are added to the model by using dummy variables with a two-day event window (the announcement day and the day after). As a robustness check, we allow for possible rumors to have an effect and use a three-day event window instead. Another robustness analysis relates to the stability of the parameter estimates during the sample period.

Our results suggest that many policy decisions have had significant effects in the European bond market. The announcement of the ECB's SMP and OMTs have had a significant negative effect on yield spreads in all of the seven euro-area countries considered in this study. At the same time, we do not find lasting impact of the liquidity support decisions on yield spreads, and the same applies for the ECB's Covered Bond Purchase Program (CBPP). The latter is understandable, given that the CBPP was directed to support banks' market funding at the early phase of the crisis, when the European sovereign debt markets were still relatively calm.

The financial support packages have typically decreased bond spreads in receiving countries, but these effects are statistically rather weak. At the same time, the financial support programs have had a relatively significant positive effect on bond spreads in the guarantor countries. This may reflect the fact that financial support programs are de facto risk-sharing mechanisms between the euro-area member countries. The decisions regarding the European Financial Stability Facility (EFSF) seem to have decreased the yields, while the decision on the European Economic Recovery Plan (EERP) had a significant increasing effect on the yields of most of the countries, as expected. Other policy decisions, mainly related to the strengthening of the growth and stability pack and to improving the fiscal discipline, have not had a lasting impact on bond spreads. Our data sample also includes the Greek debt restructuring, for which we find a very strong negative effect on yields in Greece. In other

[1] See, e.g., Arghyrou and Kontonikas (2012), Barbosa and Costa (2010), Barrios et al. (2009), Favero, Pagano, and von Thadden (2010), Fontana and Scheicher (2010), Manganelli and Wolswijk (2009), Pozzi and Woslwijk (2012), and Sgrerri and Zoli (2009).

countries—such as France, Italy, and Ireland—it had a significant positive effect on sovereign spreads.

As for the risk factors, we find that the role of macroeconomic news, which we use to proxy country-specific credit risk, has been relatively unimportant for most of the countries in our study. At the same time, we have found relatively strong evidence that during the crisis (after May 2010), bond spreads became more sensitive to changes in the risk appetite of the markets and to changes in liquidity risk. We also found some evidence of increased interdependency of the bond spreads after May 2010.

Our paper contributes to the literature studying the determination of sovereign yields in Europe, in that it focuses on a wide range of policy and macroeconomic news factors. In contrast to many other papers, we use high-frequency data, which allows us to focus on the announcement effects. Our paper also contributes to the literature on large-scale asset purchases, albeit our focus is limited to the impact of the ECB's asset purchase announcements on sovereign bond prices only. For instance, Krishnamurthy and Vissing-Jorgensen (2011, 2013) find that announcements of U.S. Federal Reserve quantitative easing programs typically have had a negative effect on Treasury yields as well as on corporate bonds and agency mortgage-backed securities (MBS). Rai (2013) has found that the U.S. Federal Reserve's "unconventional" policy initiatives have been effective in reducing market spreads, yet somewhat less so in reducing bond spreads. Most effective have been the policies that broadened the range of collateral eligible for secured funding from the Federal Reserve. At the same time, fiscal policy announcements led, if anything, to increases in spreads. Our results suggest that the announcement of central bank asset purchases directed to the stressed sovereign markets can also have a rather large effect on bond spreads, in line with, e.g., Gagnon et al. (2011), Hamilton and Wu (2012), and Krishnamurthy and Vissing-Jorgensen (2011, 2013) for the United States.

The rest of the paper is organized as follows. The second section summarizes the findings of the literature related to our paper. Our empirical model is presented in the third section, and the estimation results of the empirical model are presented in the fourth section. The fifth and final section concludes our findings.

2. Determinants of the Sovereign Bond Yields

There exists a vast literature studying the factors that determine the yields of the euro-area sovereign bonds. The earlier literature focused on understanding the convergence in the euro-area sovereign bond yields after introducing the EMU. The more recent literature has been trying to explain the fast divergence of the yields in the same set of sovereign bonds.

In this section we first take a closer look at the evolution of the euro-area government bond yields. We then provide some theoretical background for the empirical studies explaining the determinants of the sovereign bond yields and finally summarize the main results of the empirical literature.

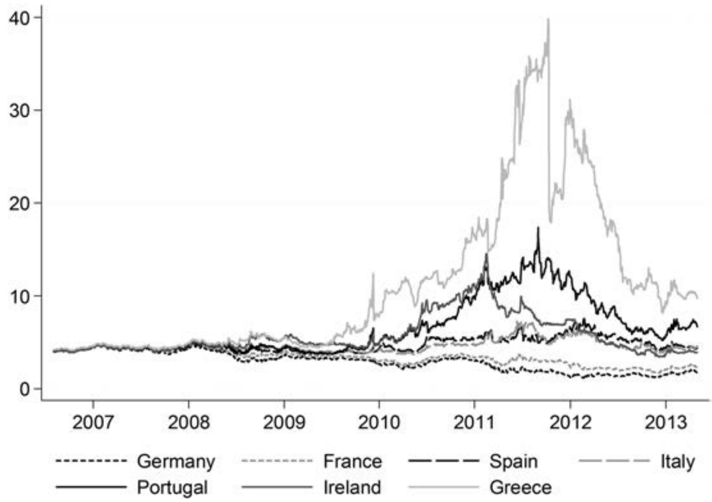
2.1 Evolution of Euro-Area Government Bond Yields and Policies

After the introduction of the euro, the yields of the euro-area sovereign bonds converged rapidly. At that time, this development was believed to be fairly natural. Given that there was no longer exchange rate and inflation risk, it was quite understandable that the yields were decreasing. Liquidity and credit risk decreased as well, along with the falling cost of public debt. The phase of convergence was followed by a few years of apparent harmony, and the credit market focused more on corporate bonds and other "more exciting" debt instruments.

The markets turned their focus to the euro-area sovereign debt market again after the collapse of Lehman Brothers in September 2008. Figure 1 presents the evolution of sovereign bond yields for selected euro-area countries. It can be seen that the development during the past five years has been dramatic. It appears that there has been a regime shift in the pricing of the European sovereign bonds.

When the financial crisis intensified and spread to the real economy, the euro-area governments provided support for the banking sector. Fiscal stimulus measures, such as the European Economic Recovery Plan, were implemented in order to support failing macroeconomies. However, the strength of the spillovers from financial markets to the real economy was surprisingly strong, leading to

Figure 1. Yields of the Ten-Year Government Bonds for Selected Euro-Area Countries



deterioration of macroeconomic fundamentals in many euro-area countries and significant widening of the euro-area bond yields since late 2008.

Long-term interest rates started to rise, especially in those countries that had accumulated deficits during the tranquil times or otherwise had a banking sector that was particularly vulnerable to international financial crises. The crisis hit especially hard in Greece, where debt markets have been under severe stress since mid-2010. Later on, the debt crisis started to spread also to other financially vulnerable euro-area countries with well-known consequences. Greece, Ireland, Portugal, and most recently Cyprus were driven out from the markets and received funding from the European crisis-resolution mechanisms and the International Monetary Fund (IMF). In connection with widening spreads, the large euro-area countries Spain and Italy also suffered from deteriorating market sentiment driving up the yields and hampering their ability to roll over debt and finance their deficits at sustainable rates. Sovereign debt crises also spread to the banking system, causing interbank markets to dry up, and revealed the vulnerability of the European banking system to the sovereign risk.

Euro-area sovereign crises have led to a number of policy actions and initiatives by the European fiscal authorities, including the decision to establish the European Stability Mechanism as a follow-up to the European Financial Stability Facility and the European Financial Stability Mechanism. These crisis-resolution mechanisms were created in order to provide financing to troubled euro-area sovereigns that faced financing difficulties. Financing from these mechanisms would be conditional on macroeconomic adjustment programs, in line with the IMF practice.

A number of important policy initiatives have also been directed to improve the fiscal discipline within the euro area. For example, Europe has agreed on the so-called fiscal compact which will strengthen coordination of fiscal and economic policy; the European semester enables the European Commission to view member states' budgetary and structural policies before their implementation; and the Macroeconomic Imbalances Procedure aims at detecting excessive macroeconomic imbalances. From the institutional perspective, all these policies have a common goal of enforcing commitment to common rules and improving surveillance power in economic and financial matters by the union. The fiscal compact aims to bring the balanced budget rules to Europe in the same way as in the United States, where many states and local communities are subject to balanced budget rules.

At the same time, the ECB has used a series of non-standard policy measures to contain pressure to the financial system by providing both short-term and long-term liquidity support and has lowered its main policy rate to historically low levels. Enhanced credit support measures have included lengthening of the maximum maturity of refinancing operations, extension of the eligible collateral list, provision of liquidity in foreign currencies, and provision of unlimited liquidity at a fixed rate. The ECB has also acquired private and public bonds within its Covered Bond Purchase Program and Securities Market Program, which were tailored to support the liquidity of the money market and the transmission of monetary policy. As the speculation over the future of the European monetary union intensified in late 2011 and early 2012, ECB President Mario Draghi gave his "whatever-it-takes" speech in July 2012, followed by the announcement of the ECB's Outright Monetary Transactions in September of the same year.

But have these policy initiatives been effective? One way to look at it is to analyze the impact of the different policy announcements on sovereign bond yields. However, in order to estimate reliably the policy announcement effects, the proper choice of conditioning variables is important.

2.2 Theoretical Background

The empirical studies explaining the determinants of the sovereign bond yields often rely (loosely) on the structural model of Merton (1974). The key idea behind Merton's model is that a risky zero-coupon bond has the same payoff structure as a risk-free bond plus a put option on the firm's value, with a strike price equal to the face value of the firm's debt. Therefore, the value of the put option is the cost of eliminating the credit risk, and the default-risky bonds can hence be priced by using standard option pricing theory such as the Black-Scholes equation.

The model is relying on an assumption that the firm's default is triggered when the firm value falls below some threshold and that this threshold is a function of the amount of debt that the firm has. This relates the corporate credit risk to its fundamentals such as leverage ratio and the volatility of the firm value. The third factor that determines the price of a default-risky bond in the Merton model is the risk-free interest rate.

The original Merton model has been extended in various ways. The extension that is the most relevant to us is the one by Gapen et al. (2008). While the original Merton model considers the corporate bonds, Gapen et al. (2008) extend the model for the default-risky sovereign bonds. Gapen et al. (2008) state that the main factors underlying sovereign credit risk are the volatility of sovereign assets and a country's leverage.

Even though the Merton model has had an influence on some of the empirical studies on yield determination, most of the papers are purely empirical.[2] There exists ample empirical evidence, discussed in more detail in section 2.3, which suggests that besides the

[2]In their recent paper, Arghyrou and Tsoukalas (2011) find the lack of theoretical background troublesome and propose a new theoretical framework for the European debt crisis. The key idea in their model is that in the currency union the systemic macroeconomic risks cannot be solved by currency adjustments,

credit risk, sovereign yields are affected by liquidity risk, by general risk appetite, and perhaps by the interaction of these three factors.

2.3 Empirical Evidence on Yield Determination

The empirical evidence on the determinants of the European sovereign bond yields is extensive yet mixed. Different factors have been found to be relevant depending on the set of countries under study, time period, data frequency, estimation methodology, or proxies for the different risk factors. One thing that almost all studies seem to agree upon, however, is that there exists a common risk factor that reflects investors' changing attitudes towards risk (Arghyrou and Kontonikas 2012; Barrios et al. 2009; Favero, Pagano, and von Thadden 2010; Manganelli and Wolswijk 2009; Pozzi and Woslwijk 2012; Sgherri and Zoli 2009). The rationale behind these findings is that higher uncertainty increases investors' risk aversion and this causes them to restructure their portfolios. Typically this is done in favor of bonds with safe-haven status, and hence the yields of the bonds with higher default risk increase.

Even though it is widely agreed that such a factor of general risk attitude or appetite exists, there is still an ongoing debate on how to measure this factor and what are the underlying causes of the changes in investors' risk aversion. Manganelli and Wolswijk (2009) suggest that the ECB policy rate is the key issue driving aggregate risk perception. Others concentrate less on the causes of uncertainty and settle for measuring risk attitude with some financial market variables that describe uncertainty in the global financial markets, such as the S&P 500 implied volatility index, i.e., VIX[3] (Arghyrou and Kontonikas 2012; Beber, Brandt, and Kavajecz 2009; Borgy et al. 2011; Gerlach, Schulz, and Wolff 2010) or the spread between the yields of U.S. corporate bonds

but are instead diverted to the sovereign debt market and hence cause increasing default risk.

[3]The Chicago Board Options Exchange Volatility Index, i.e., VIX is constructed by using the implied volatility of the S&P 500 index options with different strikes. It reflects the expected movement in the S&P 500 index over the next thirty-day period and is hence typically used as an index of market sentiment or fear.

against U.S. Treasury bills (Attinasi, Checherita, and Nickel 2009; Favero, Pagano, and von Thadden 2010; Haugh, Ollivaud, and Turner 2009).

Besides the common market risk factors, the models of yield determination also include country-specific risk factors. The most important of those is the sovereign credit risk. Most of the existing studies have used data sets with low frequency (monthly or quarterly). This has some advantages, such as being able to use the macroeconomic statistics (e.g., debt-to-GDP ratio, budget-deficit-to-GDP ratio, debt service ratio, and current account balance or expected fiscal positions by using forecasts on those same variables) that are released only rarely to describe the fiscal position and hence proxy the credit risk of the country (Aßmann and Boysen-Hogrefe 2012; Arghyrou and Kontonikas 2012; Attinasi, Checherita, and Nickel 2009; Barrios et al. 2009; Haugh, Ollivaud, and Turner 2009). Some papers have also used a country's credit rating as a proxy for credit risk (e.g., Manganelli and Wolswijk 2009). The studies that use higher-frequency data typically use other measures for credit risk, such as credit default swap (CDS) premia[4] (Arghyrou and Kontonikas 2012; Barrios et al. 2009; Beber, Brandt, and Kavajecz 2009), because the variables that change as infrequently as once in a month or quarter would probably not have an effect on noisy daily yields.

The empirical evidence on the relevance of the fiscal imbalances is mixed. However, an increasingly common finding in the literature is that expected fiscal deficits have an effect on long-term government bond yields (Arghyrou and Kontonikas 2012; Attinasi, Checherita, and Nickel 2009; Barbosa and Costa 2010; Gerlach, Schulz, and Wolff 2010; Sgherri and Zoli 2009). A good summary of the findings of this literature is provided by Haugh, Ollivaud, and Turner (2009). The impact of CDS premia on bond yields has been found to be positive. However, their use is somewhat problematic because of the potential endogeneity problems. Being a tradable instrument in the same

[4]A credit default swap is an agreement between two parties in which one can buy "insurance" against a potential default of a bond. The buyer of the CDS makes a series of payments (i.e., premia) to the seller, and in case of default the seller will compensate the buyer for the losses incurred in the underlying bond contract.

markets, prices of credit default swaps are likely to be determined by the same factors as the bonds themselves.[5]

Another potential risk factor explaining the yield differentials is the liquidity risk. If the bond markets are large and deep, investors are able to find counterparties more easily and execute trades when they choose. In liquid markets it is also less likely that prices will change due to individual transactions. Due to these reasons, an investor will require a smaller premium in terms of the yield. Therefore, the liquidity risk premium measures the extra interest rate component an investor requires for bearing the liquidity risk.

Liquidity is typically considered hard to measure. The used proxies have been, e.g., bid-ask spreads (Aßmann and Boysen-Hogrefe 2012; Fontana and Scheicher 2010; Gómez-Puig 2009) or the size of the government bond markets (Arghyrou and Kontonikas 2012; Attinasi, Checherita, and Nickel 2009; Bernoth, von Hagen, and Schuknecht 2012; Gómez-Puig 2009; Haugh, Ollivaud, and Turner 2009), or some other measures such as the yield spread between bonds issued by KfW and German government bonds, used by Schwarz (2010).

The findings on the role of the liquidity risk seem to be mixed. Some find liquidity risk to be an important factor for yield determination (Arghyrou and Kontonikas 2012; Attinasi, Checherita, and Nickel 2009; Barrios et al. 2009; Favero, Pagano, and von Thadden 2010; Gerlach, Schulz, and Wolff 2010; Gómez-Puig 2009; Manganelli and Wolswijk 2009; Schwarz 2010; Sgherri and Zoli 2009), whereas sometimes it has not been found to have a significant impact on yields (Bernoth and Erdogan 2012; von Hagen, Schuknecht, and Wolswijk 2011).

Other variables that have been included in the models of yield determination are, e.g., the risk-free interest rate (e.g., Fontana and Scheicher 2010; Oliveira, Curto, and Nunes 2012), local stock market indices (e.g., Oliveira, Curto, and Nunes 2012), volatility of the local asset markets (e.g., Barrios et al. 2009; Fontana and Scheicher 2010, Oliveira, Curto, and Nunes 2012), foreign exchange market

[5]Bond spreads and CDS premia have been found to move in tandem in the long run, yet there is some evidence that the CDS market tends to move ahead of the bond market in pricing adjustment, meaning that past values of CDS premia help to forecast bond yield spreads (see, e.g., Palladini and Portes 2011).

volatility (e.g., Barrios et al. 2009; Fontana and Scheicher 2010), and term structure variables (Fontana and Scheicher 2010; Oliveira, Curto, and Nunes 2012). None of these variables has gained a status of belonging to the set of "core risk factors" that includes the three variables mentioned above.

One reason that could explain the mixed empirical findings is that the relevance of the different risk factors changes over time, as suggested by, e.g., Aßmann and Boysen-Hogrefe (2012), Arghyrou and Kontonikas (2012), Barrios et al. (2009), Oliveira, Curto, and Nunes (2012), and many others. It might not be very surprising that the risk factors would have changed between the pre-EMU, pre-crisis, and crisis periods, but it has also been suggested that there have been two or three regime shifts during the financial crisis (Barbosa and Costa 2010; Caceres, Guzzo, and Segoviano 2010).

Many studies (e.g., Arghyrou and Kontonikas 2012; Bernoth, von Hagen, and Schuknecht 2010) confirm that the markets have been penalizing bad fiscal positions more during the financial crisis. Also, the required liquidity risk premium has been found to be higher during the crisis (Aßmann and Boysen-Hogrefe 2012). The relevance of the global investors' risk aversion has also increased during the crisis (Arghyrou and Kontonikas 2012; Barrios et al. 2009; Bernoth, von Hagen, and Schuknecht 2010; Haugh, Ollivaud, and Turner 2009; Sgherri and Zoli 2009) and the market has also priced the interaction between risk aversion and credit and liquidity risks (Manganelli and Wolswijk 2009; von Hagen, Schuknecht, and Wolswijk 2011).

Contagion in the euro-area sovereign markets has been studied, e.g., by Arghyrou and Kontonikas (2012), Caceres, Guzzo, and Segoviano (2010), and Claeys and Vašíček (2012). Arghyrou and Kontonikas (2012) use monthly ten-year bond data for ten euro-area countries covering the period from January 1999 to February 2010 and find that many EMU countries, especially Portugal, Ireland, and Spain, have experienced contagion from Greece. Claeys and Vašíček (2012) also find significant spillover effects in these countries. According to Caceres, Guzzo, and Segoviano (2010), after September 2008, risk of contagion was also an important factor in pricing the euro-area sovereign bonds.

Of the number of papers examining the yield determination during the financial crisis, the paper that comes closest to ours is that of Attinasi, Checherita, and Nickel (2009). They study the determinants of the sovereign bond yields in ten euro-area countries during the period from July 31, 2007, to March 25, 2009. Besides studying the risk factors, they examine the announcements of the government rescue packages for banks. They find that the announcements of the rescue packages have caused repricing of the sovereign risk, but the actual amount of the package has not had a significant effect on government bond yields. Therefore, the results of Attinasi, Checherita, and Nickel (2009) suggest that the stress in the national banking sector was transferred to the public sector through governments' rescue packages.

Instead of using announcements on banking rescue packages, this paper contributes to the literature by studying the impact of the announcements on various political decisions made in Europe during the financial and sovereign debt crises. To the best of our knowledge, the effect of a wide range of policy decisions on euro-area sovereign yields has not been studied before, yet such studies have been conducted with the U.S. data.[6] Our paper differs from others also by data frequency. In order to be able to capture the policy impact from other factors in the bond markets, we need to use daily data. Other papers typically concentrate on lower-frequency dynamics (weekly, monthly, or quarterly) of the sovereign bond markets. Our empirical model on yield determination and policy effects is explained more carefully in the next section.

3. Empirical Model on Yield Spreads

This section presents the empirical model used for studying the determinants of the yield spreads on the European sovereign bonds. We first describe the financial market data set, then the policy decisions of interest, and finally the econometric model to be estimated.

3.1 Financial Market and Macroeconomic Data

Our data set of dependent variables includes daily yield spreads between the benchmark ten-year government bond[7] and the ten-year

---

[6]Eser and Schwaab (2013) focus only on the effects of the ECB's SMP program on yield changes and find relatively large and significant announcement effects.

[7]All the data were obtained from Thomson-Reuters and Bloomberg.

euro swap rate from January 1, 2007, to September 30, 2013 for the following countries: Germany (DE), France (FR), Spain (ES), Italy (IT), Portugal (PT), Ireland (IE), and Greece (GR).[8] The dependent variable is henceforth denoted as $y_{i,t}$ for the country i, where $i = \{DE, FR, ES, IT, PT, IE, GR\}$ and day t. The group of countries was selected such that it includes both countries in stress and those that are healthier. The selected countries also vary in terms of the size of the economy.

The ten-year bond maturity was chosen because it has been the most common horizon used in the similar literature; also, the markets for ten-year bonds are relatively active. The euro swap rate (e.g., Beber, Brandt, and Kavajecz 2009) and German government bond yield (e.g., Arghyrou and Kontonikas 2012; Haugh, Ollivaud, and Turner 2009) have both been used as a measure for the risk-free interest rate in the literature. From these two we chose to use the first one, because the euro swap rate has some advantages compared with use of the German bund yield. First, it allows for adding Germany in the analysis and second, according to, e.g., Beber, Brandt, and Kavajecz (2009), it is commonly seen as the preferred measure of a risk-free rate by market participants.

As discussed in sub-section 2.3, there exists wide empirical evidence that the sovereign bond yields are determined by three main risk factors: credit risk, liquidity risk, and general risk appetite. Following the literature, we attempt to capture these risk factors by using their relevant proxies as explanatory variables in our regression.

We proxy a country's credit risk by a set of macroeconomic indicators, including different measures of the country's fiscal and economic stance—such as budget balance, current account balance, GDP, and unemployment—as well as confidence indicators, such as consumer and business confidence.[9]

---

[8]Due to lack of data on some explanatory variables, the dates are not exactly these for all countries.

[9]In the high-frequency analysis such as ours, the country credit risk has been typically measured with CDS premia (e.g., Arghyrou and Kontonikas 2012, Barrios et al. 2009, and Beber, Brandt, and Kavajecz 2009). However, as discussed in sub-section 2.3, the use of CDS premia might introduce some endogeneity problems in the estimation. This was, in fact, the case in our model, and hence we decided not to measure credit risk with CDS premia.

However, instead of using macroeconomic variables that change only once per month or quarter as a regressor for daily bond spread, we incorporate the macroeconomic variables in the form of news announcements.[10] Our macroeconomic news data set includes the scheduled releases of the selected macroeconomic indicators published in the Bloomberg World Economic Calendar. Besides the released figure of a macro indicator k (denoted as $A_{t,i,k}$), the data also comprises the market forecast for each released figure, denoted as $F_{t,i,k}$. The market forecast is the median of all the individual survey forecasts that Bloomberg collects from the market agents before the announcement. The available macroeconomic variables differ between countries somewhat, and the selected indicators for each country are presented in table 5 in appendix 1.

Naturally, the market should only react to new information and, hence, only part of the announced macroeconomic figure that surprises the market—i.e., news—should affect the bond spreads. Following the literature, news is defined as standardized surprise $S_{t,i,k} = (A_{t,i,k} - F_{t,i,k})/\hat{\sigma}_{k,i}$, where $\hat{\sigma}_{k,i}$ is the standard deviation of the surprises $(A_{t,i,k} - F_{t,i,k})$ of macroeconomic indicator k estimated from the entire sample period for country i. We combine the news of different indicators in the single variable $MNEWS_{t,i}$ for each country separately. This variable takes a non-zero value on those days t when there is a news announcement.[11]

The second country-specific risk factor, liquidity risk, is measured by the bid-ask spread[12] of the ten-year bond yield, henceforth denoted as $BAS_{t,i}$. As for the general risk aversion, we use the VIX (VIX_t) to proxy the risk appetite of the global investors and the iTraxx Europe index[13] ($ITRX_t$) to proxy the general risk atmosphere in the European debt markets. We also considered other indicators describing uncertainty in the financial markets, but they all turned

[10] There exists a vast literature on the macroeconomic news announcement effects on bond yields and other financial market data. See, e.g., Andersen et al. (2003).

[11] Before combining the indicators, the surprises of the indicators for which the negative (positive) surprise indicates good (bad) news, such as in the case of unemployment, were multiplied by −1.

[12] Bid-ask spreads were collected from Reuters.

[13] The Markit iTraxx Europe index comprises 125 equally weighted credit default swaps on investment-grade European corporate entities.

out to be insignificant and were hence left out of the final model specification. These indicators were the VSTOXX index[14] to describe the uncertainty in the European stock markets, the one-month implied volatility of the EUR/USD exchange rate to represent the stress in the currency markets, the squared bond yield changes to measure the uncertainty in a particular sovereign bond market, and the weekly CISS index[15] by Hollo, Kremer, and Lo Duca (2012) to describe the level of systemic risk at the European financial markets.

Besides the different risk factors, we considered including the three-month Euribor interest rate to proxy the risk-free short-term interest rate in the model, but it turned out to be statistically insignificant and was hence left out of the final model specification.

In order to capture direct dependence between different countries' yield spreads and possible contagion effects between the countries, we include the lagged bond yield spreads of all the countries as explanatory variables. We recognize that this is only a crude approximation to capture the contagion effects in a noisy daily data. Besides these risk factors and the contagion variables, our model includes dummy variables for the policy decisions. These are discussed in more detail in the next sub-section.

3.2 Policy Decisions

All the European-wide policy decisions we are interested in are listed in table 1. To study the impact of these events, we create dummy variables for each policy decision such that each dummy variable equals one on the day the policy decision was announced and on the day after. The motivation behind this two-day window is that in some cases the decision was reached in the evening when the markets were already closed for that day. Hence the market reacts to the announcement only in the day following the announcement. Also, it

[14]The VSTOXX index measures the implied volatility of the EURO STOXX 50 index options and is created jointly by Deutche Borse and Goldman Sachs to measure volatility in the euro area.

[15]The CISS index is a composite index using information from the total of fifteen individual financial stress measures from financial intermediaries (banks and non-banks), money markets, securities (stocks and bonds), and foreign exchange markets. Linear interpolation is used for changing weekly data frequency to daily. This index is maintained and updated frequently by the ECB.

Table 1. Categories of the Policy Decisions

ECB Collateral Requirements Relaxed ($ECBcrl_t$) Oct. 15, 2008; May 3, 2010; Jul. 7, 2011; Dec. 8, 2011; Mar. 8, 2012; Jun. 22, 2012; Sep. 6, 2012; Dec. 19, 2012; May 2, 2013; Jul. 5, 2013
ECB Collateral Requirements Restricted ($ECBcrs_t$) May 25, 2007; Nov. 26, 2008; Apr. 8, 2010; Feb. 28, 2012; Jul. 20, 2012; Mar. 22, 2013; Jun. 28, 2013
ECB Liquidity Support ($ECBls_t$) Aug. 22, 2007; Sep. 6, 2007; Mar. 28, 2008; Oct. 7, 2008; May 7, 2009; Aug. 4, 2011; Oct. 6, 2011; Dec. 8, 2011
ECB Covered Bond Purchase Program ($ECBcb_t$) Jun. 4, 2009; Oct. 6, 2011
ECB Securities Market Program ($ECBsmp_t$) May 10, 2010
ECB Outright Monetary Transactions Program ($ECBomt_t$) Sep. 6, 2012
ECB Draghi "Whatever-It-Takes" Speech ($ECBdhi_t$) Jul. 26, 2012
Support Package Request ($SPreq_t$) Nov. 21, 2010; Apr. 8, 2011; Jun. 25, 2012; Jun. 27, 2012
Support Package Decisions ($SPdec_t$) Apr. 12, 2010; May 10, 2010; Nov. 28, 2010; May 16, 2011; Jul. 21, 2011; Feb. 20, 2012; Jul. 20, 2012; Mar. 25, 2013
Support Package Conditions Relaxed ($SPcrl_t$) Nov. 27, 2012; Mar. 16, 2013
Greece Debt Restructuring ($Drst_t$) Mar. 9, 2012
Decisions on ESM (ESM_t) Oct. 28, 2010; Nov. 29, 2010; Dec. 16, 2010; Mar. 21, 2011; Feb. 2, 2012; Mar. 30, 2012; Jul. 9, 2012
Widening of the Mandate of EFSF/ESM ($EFSF_t$) Jun. 20, 2011; Jul. 21, 2011; Oct. 26, 2011; Mar. 30, 2012
European Economic Recovery Plan ($EERP_t$) Nov. 26, 2008
Other Decisions Related to European Economic Governance (OD_t) May 27, 2009; Sep. 29, 2010; Mar. 11, 2011; Mar. 25, 2011; Nov. 8, 2011; Dec. 19, 2011; Mar. 2, 2012; Jun. 29, 2012; Dec. 14, 2012
Notes: The table presents the policy announcements divided into corresponding categories.

might be that the effect of some of the decisions on sovereign risk are difficult to judge, and hence the market is processing the decision longer than one day. In some cases, it is also likely that the market already anticipates the forthcoming decision on the day before. Therefore, we run a robustness check with a three-day window that allows for both pre- and post-announcement-day drifts in the yield spreads.

Altogether we have identified a very large number of important policy decisions since January 2007, as documented in appendix 2. We divide the policy decisions into sixteen categories and combine the dummy variables belonging to the same category to reduce multicollinearity problems in the estimation and improve the economic interpretation of the results.

The first seven categories include the important policy decisions made by the ECB. The ECB's collateral requirements were changed in a number of occasions. We capture separately the decision that eased and restricted the collateral requirements by dummy variables *ECBcrs* and *ECBcrl*, respectively. The dummy variable related to the ECB's liquidity support decisions is denoted as $ECBls_t$. The policy announcements related to the ECB's Covered Bond Purchase Program and Securities Market Program are studied separately, and the dummy variables for these categories are denoted as $ECBcb_t$ and $ECBsmp_t$, respectively. Finally, we allow a separate dummy variable for the announcement of the ECB's OMTs, *ECBomt*, in September 2012 and ECB President Mario Draghi's "whatever-it-takes" speech in July 2012.

As for the rest of the groups, we try to disentangle the decisions that have implied a possible launch of the new financial support program (requests for the support packages, denoted as $SPreq_t$, and the announcements related to the final decisions of the support packages, denoted as $SPdec_t$, are studied separately), announcements related to the creation of the ESM (denoted as ESM_t), decisions on widening of the EFSF mandate (denoted as $EFSF_t$), announcement of the European Economic Recovery Plan (denoted as $EERP_t$), and other decisions related to European economic governance (denoted as OD_t). These other decisions are primarily related to strengthening of the Stability and Growth Pact, and improving fiscal discipline and fiscal coordination in the euro area. For example, Europe has agreed on the so-called fiscal compact, which will strengthen coordination of fiscal and economic policy; the European semester enables the European Commission to view member states' budgetary and structural policies before their implementation; and the Macroeconomic Imbalances Procedure aims at detecting excessive macroeconomic imbalances.

3.3 ECB Interest Rate Decisions

Compared with the other ECB policy decisions, the decisions related to the interest rates are different in a sense that, similarly to the macroeconomic news described in section 3.1, the announcement day and time of the interest rate decisions are known beforehand. The ECB interest rate decisions (and other monetary policy decisions) are made by the Governing Council of the ECB, which meets twice a month. The monetary policy decisions are made at the first meeting of each month, typically taking place on the first Thursday of the month. Hence, market agents are able to form expectations on the released decision before it is announced. Besides collecting the survey forecasts for macroeconomic statistics, Bloomberg also collects the market agents' forecasts of the ECB interest rate decision. By using the market forecast for each released interest rate decision, we can create an interest rate surprise variable $ECBir_t = (A_{t,ir} - F_{t,ir})/\hat{\sigma}_{ir}$, where $A_{t,IR}$ is the decision on the interest rate made at day t, $F_{t,ir}$ is the market forecast for the interest rate, and $\hat{\sigma}_{IR}$ is the standard deviation of the interest rate surprises estimated from the entire sample period. Hence, unlike the other policy announcement variables that are two- or three-day dummies, $ECBir_t$ takes a value of the interest rate surprise on those days when the ECB makes interest rate decisions, and zero otherwise.

3.4 The Model

To study the determinants of the yield spreads of the European sovereign bond markets, and the impact of the fiscal and monetary policy decisions in Europe during the debt crisis, we estimate the following model (1) with the ordinary least squares estimation method separately for all the countries ($i = Germany$, $France$, $Spain$, $Italy$, $Portugal$, $Ireland$, $Greece$).

The dependent variable and the explanatory variables are explained in sub-sections 3.1 and 3.2. Unit-root tests[16] suggest that the dependent variable is non-stationary for most of the countries and hence the model is estimated in first differences.[17] α is a constant, β_i for $i = \{DE, FR, ES, IT, PT, IE, GR\}$ are parameters that describe the potential contagion effects between countries, γ_j for $j = \{MNEWS, BAS, VIX, ITRAXX\}$ are parameters for controlling the effects of the different risk factors, δ_k for $k = \{IR, CRL, CRS, LS, CB, SMP, OMT, DHI\}$ capture the impact of the ECB policy decisions, ϕ_l for $l = \{SPreq, SPdec, SPrl, DEBTrst, ESM, EFSF, EERP, OD\}$ give the impact of the other policy decisions, and $\varepsilon_{i,t}$ is the error term of the model. The Newey-West standard errors (with thirty lags) are used because of the undefined form of autocorrelation and heteroskedasticity in the residuals.

$$
\begin{aligned}
\Delta y_{t,i} = \alpha_i &+ \sum_{i=1}^{7} \beta_i \Delta y_{t-1,i} + \gamma_{MNEWS} MNEWS_{t,i} \\
&+ \gamma_{BAS} \Delta BAS_{t,i} + \gamma_{VIX} \Delta VIX_t + \gamma_{ITRX} \Delta ITRX_t \\
&+ \delta_{ECBir} ECBir_t + \delta_{ECBcrl} ECBcrl_t + \delta_{ECBcrs} ECBcrs_t \\
&+ \delta_{ECBls} ECBls_t + \delta_{ECBcb} ECBcb_t + \delta_{ECBsmp} ECBsmp_t \\
&+ \delta_{ECBomt} ECBomt_t + \delta_{ECBdhi} ECBdhi_t + \phi_{SPreq} SPreq_t \\
&+ \phi_{SPdec} SPdec_t + \phi_{SPrl} SPrl_t + \phi_{DEBTrst} DEBTrst_t \\
&+ \phi_{ESM} ESM_t + \phi_{EFSF} EFSF_t + \phi_{EERP} EERP_t \\
&+ \phi_{OD} OD_t + \varepsilon_{t,i} \qquad (1)
\end{aligned}
$$

4. The Results

In this section we present the estimation results of the empirical model as described above. The main results are presented in table 2.

[16] The results for unit-root tests are available from the authors upon request.

[17] Similar findings, albeit from a different sample, can be found in Fontana and Scheicher (2010). We could have also considered a co-integration analysis, but given the short sample with possible breaks in the series, we considered it to be out of the scope of this paper. Our focus is on policy effects and not on the yield dynamics per se.

Table 2. Estimation Results with a Two-Day Event Window

	Germany	France	Spain	Italy	Portugal	Ireland	Greece
γ_{MNEWS}	0.077	−0.026	0.021	−0.027	0.001	−0.029	−0.135**
γ_{BAS}	−0.003	0.136***	0.045	0.053	0.445***	0.124***	0.494***
γ_{VIX}	0.096**	0.046	−0.003	0.031	0.022	0.045	0.013
γ_{ITRX}	−0.262***	0.103*	0.333***	0.372***	0.191***	0.183***	0.085***
β_{DE}	−0.222***	−0.131***	−0.033	−0.025	−0.069	−0.095***	−0.041*
β_{FR}	0.001	−0.073	−0.050	−0.107*	0.045	0.097**	0.016
β_{ES}	0.011	−0.030	0.088**	−0.026	−0.059	0.034	0.068
β_{IT}	−0.159***	−0.015	−0.004	0.074	0.028	−0.031	−0.013
β_{PT}	−0.040	−0.096	−0.086*	−0.095*	0.136***	−0.024	0.052*
β_{IE}	0.046	0.062*	0.046*	0.076**	−0.000	0.097*	−0.052
β_{GR}	−0.004	0.030*	−0.033**	0.005	−0.012	−0.019	0.054*
δ_{ECBir}	0.227	0.168	0.055	0.054	0.093**	0.086	−0.059
δ_{ECBcrl}	0.175	−0.373**	−0.089	0.111	−0.315	0.016	0.570
δ_{ECBcrs}	−0.081	−0.004	0.097	−0.211	0.405	0.073	0.278
δ_{ECBls}	0.312	0.250	−0.123	0.124	−0.096	−0.420	−0.148
δ_{ECBcb}	0.259	−0.056	−0.100	−0.035	0.165	0.424	0.265
δ_{ECBsmp}	−0.756***	−0.864**	−2.399***	−1.508***	−3.801***	−3.739***	−2.980***
δ_{ECBomt}	−0.841**	−0.917**	−3.714***	−2.486***	−2.790***	−0.911***	−0.393
δ_{ECBdhi}	−0.111	−1.651***	−3.122***	−2.605***	−0.481*	−0.422**	−0.438***
ϕ_{SPreq}	−0.106	0.297	0.841**	0.447	0.568**	0.073	−0.111
ϕ_{SPdec}	0.153	0.454**	0.455	0.311	−0.260	−0.708	−0.094
ϕ_{SPrl}	−0.122	−0.457***	−0.427	−0.107	−0.071	0.155**	0.325
$\phi_{DEBTrst}$	−0.502***	0.446***	−0.154	0.472***	−0.343**	0.504***	−13.10***
ϕ_{ESM}	0.193	0.033	0.310	0.203	0.068	0.860***	0.437
ϕ_{EFSF}	−0.243	−0.898	−0.931***	−0.599**	−0.325	−1.231*	−0.455
ϕ_{EERP}	1.116***	0.892***	0.595*	1.235***	−0.113	0.265	−0.157
ϕ_{OD}	−0.020	0.261	−0.242	−0.174	−0.208	−0.262	−0.057

Notes: The table presents the estimation results of the model (1). The model is estimated in differences and using Newey-West standard errors with thirty lags. *, **, and *** denote the 10 percent, 5 percent, and 1 percent significance levels, respectively.

We first summarize the findings related to the three risk factors: credit and liquidity risk and the general risk appetite, as well as the contagion variables. We then summarize the impact of the policy decisions on the sovereign bond yields, and conclude with some robustness checks.

4.1 Risk Factors and Contagion Variables

According to our estimation results (table 2), the impact of macroeconomic news is statistically significant only in the case of Greece. The negative coefficient implies that better-than-expected (worse-than-expected) macroeconomic news has reduced (increased) the bond spreads in Greece. For all the other countries, the effects are not significant. Bid-ask spreads, which are used to proxy liquidity risk, are typically positive and in most cases very significant (France, Portugal, Ireland, Greece). Of the proxies for the risk appetite, the impact of the iTraxx index is significant in all the countries, while the VIX is significant only in the case of Germany. The coefficient estimates (negative for Germany and positive for other countries) for the iTraxx index are consistent with flight-to-quality behavior of the markets. These coefficients capture the widening of the spreads between other countries and Germany, reflecting decreasing risk appetite in the bond markets as the crisis intensified. As the VIX reflects more the riskiness of the stock markets than the general risk appetite in the European debt markets, it is perhaps not so surprising that it is insignificant in most of the countries.

All in all, these results suggest that the risk appetite in the sovereign bond markets is an important price determinant in the European bond markets, clearly more important than the surprises in country-specific macroeconomic news. On the basis of coefficients' size, the Italian and Spanish bond markets seem to be most sensitive to movements in risk appetite. In the case of Portugal, Ireland, and Greece, the risk appetite does matter, but the pricing reflects significantly also the liquidity risk, as proxied by the bid-ask spreads. This seems rather natural, given the difference of the size of the bond markets in these two groups of countries.

In contrast to the importance of risk appetite and liquidity risk, the direct relationship between the high-frequency movements of the countries' bond spreads seems to be rather weak. There is some evidence of a lagged negative relationship between some countries, (e.g., Germany and Italy), which could be explained by the flight to safety. There are also some significant parameter coefficients within the countries Spain and Portugal and Greece, as well as between Greece and Germany, but it is difficult to interpret these results systematically. These results become more significant and interpretable once we allow regime shifts in the parameter estimates (see section 4.3).

4.2 Policy Decisions

The impacts of the policy decisions vary greatly (table 2), both in magnitude and in significance. The unexpected interest rate decisions of the ECB have had a significant effect only in the case of Portugal. Decisions related to the ECB's collateral policy enter significantly only in the case of France, whereby relaxation of collateral requirements has decreased the bond spreads. The impact of the ECB's liquidity support decision on ten-year sovereign bond spreads is not statistically significant in any of the countries. This could simply reflect the fact that collateral, liquidity support, and covered bond program decisions were mainly targeted to the bank's funding and liquidity problems, rather than directly to the problems in sovereign markets. Moreover, many of these decisions were made at an early phase of the global financial crises, before the European sovereign bond markets became under stress. Consequently, in comparison to, e.g., Rai (2013) for the United States, we do not find that the ECB liquidity and collateral policies had significant effects on long-term bond spreads in Europe.[18]

In contrast, the ECB policy decisions directly targeted to the European sovereign debt markets have had a significant and large impact on bond spreads. The announcement of the ECB's

[18] Note that Rai (2013) focuses on corporate bond spreads, while we study the impact of policies on sovereign bond spreads.

Securities Market Program, OMTs, and ECB President Draghi's "whatever-it-takes" speech have had a large negative effect on bond spreads in all of the seven countries in this study.[19]

Spain and Italy were affected most strongly, but coefficients are large and very significant also in Portugal, Ireland, and Greece. Consequently, in line with, e.g., Gagnon et al. (2011), Hamilton and Wu (2012), and Krishnamurthy and Vissing-Jorgensen (2011, 2013) for the United States, the ECB's announcements of large-scale asset purchase programs had a significant effect on bond spreads in Europe. At the same time, we did not find a statistically significant coefficient for the ECB's Covered Bond Purchase Program, which was specifically geared towards easing banks' market funding problems at an early phase of the financial crisis.[20] Given that the program was relatively small in size (€60 billion) and had actually ended already by June 2010, it is perhaps not surprising that we find no significant effect on the sovereign markets.

The decisions related to the financial support packages are mixed. In table 2, the decision to request financial support has typically not affected the markets significantly, except in Spain and Portugal, where the request decision has had a positive effect on bond spreads. When the decisions to grant financial support were finally agreed upon and announced publicly by the Eurogroup, the coefficient of the requesting country is always negative, albeit not statistically significant. This may reflect at least partly the fact that the decisions were largely anticipated well in advance.

In all other countries, the corresponding coefficients are positive, yet only in the case of France is the effect statistically significant. Albeit rather weak, the general drift in the bond spreads around the announcements of financial support packages seems to

[19]The SMP was announced on May 10, 2010, with the aim of addressing the malfunctioning of certain sovereign bond markets, and by the end of December 2012 the Eurosystem's SMP holdings amounted to over €200 billion. While the SMP did not include any ex ante eligibility criteria, a necessary condition for the OMTs was strict and effective conditionality attached to an appropriate EFSF/ESM program. Another important difference to the SMP was that OMTs would be ex ante unlimited.

[20]The covered bond program category includes two decisions, the decisions on the first and the second program.

reflect the risk-sharing aspect of financial support programs: countries that were acting as guarantors of the loans through the EFSF and the ESM to troubled sovereigns, faced, if anything, increasing bond spreads, and those receiving the finances faced decreasing bond spreads.

Of the remaining policy decisions, we find consistent and rather strong effects on bond spreads due to the EFSF, Greek debt restructuring, and the EERP. The decisions related to the EFSF are associated with negative coefficients in all countries, yet these coefficients are not always significant, while the announcement of the European Economic and Recovery Plan (EERP) has increased the bond spreads significantly in Germany, France, Spain, and Italy. Short-run economic stabilization probably increased the uncertainty related to the long-run sustainability of the public sector, dominating the effect on bond spreads in most of the countries. The decision on the Greek debt restructuring apparently increased the perceived riskiness of French, Italian, and Irish government bonds, but reduced that of the others. The reduction in bond spreads was very strong in the case of Greece, but it had a non-negligible negative effect also on German bunds. As a result of Greek debt restructuring, investors shifted even more to high-quality German bunds, shying away from French, Italian, and Irish bonds. Hence, to some extent, decision over Greek debt restructuring aggravated the situation in European sovereign debt markets with negative spillovers to some already stressed sovereigns.

4.3 Robustness

In table 3 we present some robustness checks with respect to the lengthening of the event window from two to three days. Lengthening the event window by one day to include also the pre-announcement day allows to control for possible rumors and anticipation effects of the policy announcements. In table 4 we consider, in addition to a three-day event window, a regime shift, where we let the parameters of the risk factors and the lagged yield spreads of the other countries change after May 2010. For this purpose, we have created another dummy variable that equals one from May 2010 onwards. More specifically, our empirical model now reads as

Table 3. Estimation Results with a Three-Day Event Window

	Germany	France	Spain	Italy	Portugal	Ireland	Greece
γ_{MNEWS}	0.080*	−0.020	0.012	−0.022	0.008	−0.026	−0.169**
γ_{BAS}	−0.004	0.139***	0.046	0.056	0.449***	0.128***	0.546***
γ_{VIX}	0.099**	0.048	0.003	0.035	0.033	0.056	0.019
γ_{ITRX}	−0.261***	0.106*	0.339***	0.377***	0.202***	0.189***	0.084***
β_{DE}	−0.223***	−0.132***	−0.035	−0.023	−0.075	−0.103***	−0.038*
β_{FR}	0.003	−0.072	−0.051	−0.109	0.040	0.100**	0.013
β_{ES}	0.012	−0.024	0.091**	−0.024	−0.027	0.045	0.077
β_{IT}	−0.159***	−0.013	0.005	0.077	0.023	−0.037	−0.029
β_{PT}	−0.040	−0.103	−0.094**	−0.102*	0.131***	−0.018	0.066*
β_{IE}	0.045	0.058	0.056**	0.084***	0.005	0.101**	−0.042*
β_{GR}	−0.003	0.030	−0.035**	0.006	−0.010	−0.014	0.055
δ_{ECBir}	0.193	0.142	0.024	0.038	−0.005	0.058	−0.047
δ_{ECBcrl}	0.040	−0.158	0.053	0.173	−0.038	0.310	0.621
δ_{ECBcrs}	−0.149**	0.025	0.148	−0.231	0.349	0.113	0.217
δ_{ECBls}	0.046	0.154	0.068	0.131	−0.193	−0.454*	−0.041
δ_{ECBcb}	0.361	0.110	0.129	0.201	0.457*	0.591**	0.265
δ_{ECBsmp}	−1.139***	−0.835***	−1.525**	−0.682	−2.280***	−1.988***	−1.195***
δ_{ECBomt}	−0.291	−0.614*	−2.586***	−2.053***	−0.651	−0.489	−0.227
δ_{ECBdhi}	0.186	−0.936***	−2.531***	−2.089***	0.853***	−0.103	−0.568***
ϕ_{SPreq}	0.094	0.077	0.604**	0.406	0.266	0.009	−0.140
ϕ_{SPdec}	0.237***	0.222*	0.214	0.080	−0.304	−0.547	−0.146
ϕ_{SPrl}	−0.103	−0.261*	0.049	−0.048	0.317	0.917**	0.264**
$\phi_{DEBTrst}$	−0.336**	−0.243	−0.163	−0.238	−0.153	−0.245	−8.038***
ϕ_{ESM}	0.239	−0.091	0.227	0.075	−0.191	0.790***	0.393*
ϕ_{EFSF}	−0.231*	−0.709	−0.500**	−0.293	−0.148	−1.112*	−0.486
ϕ_{EERP}	1.388***	1.127***	1.185**	1.637***	0.446	0.723*	0.005
ϕ_{OD}	−0.150	0.145	−0.158	−0.080	−0.060	−0.221	−0.015

Notes: The table presents the estimation results of the model (1) with a three-day (–1, 0, 1) event window for the policy decision dummies. The model is estimated in differences and using Newey-West standard errors with thirty lags. *, **, and *** denote the 10 percent, 5 percent, and 1 percent significance levels, respectively.

$$\begin{aligned}\Delta y_{t,i} = \alpha_i &+ \sum_{i=1}^{7} (\beta_i + \beta_{i\_c}) \, \Delta y_{t-1,i} \\ &+ (\gamma_{MNEWS} + \gamma_{MNEWS\_c}) \, MNEWS_{t,i} \\ &+ (\gamma_{BAS} + \gamma_{BAS\_c}) \, \Delta BAS_{t,i} + (\gamma_{VIX} + \gamma_{VIX\_c}) \, \Delta VIX_t \\ &+ (\gamma_{ITRX} + \gamma_{ITRX\_c}) \Delta ITRX_{t,i} + \mathcal{P}_t(\delta, \phi) + \varepsilon_t, \end{aligned} \tag{2}$$

where $\mathcal{P}_t(\delta, \phi)$ is shorthand for the policy dummies in our regression (see equation (1)). In equation (1) β_i presents the effects of lagged yield spreads prior to May 2010 and $(\beta_i + \beta_{i\_c})$ presents the effect after May 2010. Similar interpretation applies to the rest of the coefficients related to the risk factors.

The first observation from tables 3 and 4 is that our results with respect to policy dummies remain largely unchanged: those policy decisions that were found to be important in table 2 remain important in tables 3 and 4. Our results with respect to importance of the risk factors are also largely unchanged when we move from a two-day to a three-day event window. Most interestingly, however, when we allow for the regime shift in the effect of our main control variables to bond spreads (table 4), we observe the following: First, in the case of Germany, the surprise component of macroeconomic news shifts sign after May 2010. Prior to May 2010, the macroeconomic news had a positive effect on bond yields in Germany, but afterwards the parameter γ_{MNEWS_c} in equation (2) turns negative, leaving the combined effect close to zero $(0.127 - 0.143)$.

The positive effect of macroeconomic news prior to May 2010 probably reflects the portfolio allocation effect whereby better-than-expected macroeconomic conditions lead investors to shift from less risky bonds to more risky but potentially higher yielding stock markets. The fact that this positive effect disappears after May 2010 (coefficient being close to zero) might be caused by the safe-haven status of German bunds that dominated the dynamics of the German bond spreads after the crisis escalated.

For Greece, the negative coefficient on the macroeconomic news variable reported in table 2 seems to be entirely driven by the negative coefficient after May 2010. For other countries, we still do not find significant coefficients in either of the periods. This is possibly

Table 4. Estimation Results with a Three-Day Event Window and Regime Shift

	Germany	**France**	**Spain**	**Italy**	**Portugal**	**Ireland**	**Greece**
γ_{MNEWS}	0.127**	0.018	−0.001	−0.056	−0.003	−0.027	0.019
γ_{MNEWS_c}	−0.143*	−0.089	−0.028	0.085	−0.002	0.021	−0.257***
γ_{BAS}	−0.005	0.074**	0.008	0.034	0.289***	0.042**	0.404***
γ_{BAS_c}	0.058	0.186*	0.115*	0.367**	0.163**	0.121***	0.084
γ_{VIX}	0.077	0.005	0.020	0.028	0.028**	0.027	0.005
γ_{VIX_c}	0.047	0.136*	−0.062	0.004	−0.013	0.053	0.034
γ_{ITRX}	−0.190**	−0.051	−0.003	0.042	0.014	0.000	0.014*
γ_{ITRX_c}	−0.153	0.303***	0.728***	0.714***	0.381***	0.384***	0.152***
β_{DE}	−0.163***	−0.087*	−0.079***	−0.078***	−0.078***	−0.127***	−0.024**
β_{DE_c}	−0.037	−0.033	0.106*	0.075	0.024	0.056	−0.019
β_{FR}	−0.065	−0.226***	0.004	0.013	0.010	0.065	0.002
β_{FR_c}	0.061	0.175**	−0.057	−0.147**	0.042	0.047	0.018
β_{ES}	0.252	0.225*	−0.103	0.061	0.094**	0.044	0.017
β_{ES_c}	−0.288*	−0.281**	0.217**	−0.107	−0.163**	−0.002	0.052
β_{IT}	−0.517***	−0.224***	−0.053	−0.208***	−0.020	−0.003	−0.027
β_{IT_c}	0.424***	0.228*	0.033	0.317***	0.052	−0.049	0.013
β_{PT}	−0.322**	−0.026	0.001	−0.030	−0.060	0.079	0.078
β_{PT_c}	0.294**	−0.057	−0.066	−0.046	0.216**	−0.094	−0.022
β_{IE}	0.219	0.226*	0.084	0.122	0.025	0.062	−0.029
β_{IE_c}	−0.185	−0.174	−0.048	−0.052	−0.029	0.039	−0.023
β_{GR}	0.218	0.205	0.377***	0.270	0.386**	0.324*	0.106
β_{GR_c}	−0.225	−0.176	−0.416***	−0.271*	−0.404**	−0.346*	−0.053

(continued)

Table 4. (Continued)

	Germany	**France**	**Spain**	**Italy**	**Portugal**	**Ireland**	**Greece**
δ_{ECBir}	0.221	0.107	−0.050	−0.051	0.034	0.019	−0.085
δ_{ECBcrl}	0.106	−0.344*	−0.051	0.131	−0.333	0.072	0.567
δ_{ECBcrs}	−0.070	−0.073	−0.003	−0.277*	0.369	0.005	0.275
δ_{ECBls}	0.277	0.194	−0.271	−0.040	−0.160	−0.494	−0.198
δ_{ECBcb}	0.271	−0.090	0.038	0.137	0.230	0.443	0.307
δ_{ECBsmp}	−0.980***	−0.021	−1.033***	0.124	−3.041***	−2.829***	−2.509***
δ_{ECBomt}	−0.863**	−0.533	−2.971***	−1.661***	−2.376***	−0.525**	−0.190
δ_{ECBdhi}	−0.246	−1.372***	−2.373***	−1.892***	−0.155	−0.069	−0.272
ϕ_{SPreq}	−0.088	0.229	0.654**	0.260	0.490*	−0.027	−0.149
ϕ_{SPdec}	0.188	0.416**	0.304	0.171	−0.299	−0.760	−0.130
ϕ_{SPrl}	−0.073	−0.530***	−0.633	−0.286	−0.175	0.078	0.272
$\phi_{DEBTrst}$	−0.412***	0.470***	−0.256**	0.448***	−0.377**	0.457***	−13.07***
ϕ_{ESM}	0.236	0.045	0.215	0.155	0.062	0.835***	0.419
ϕ_{EFSF}	−0.372	−0.659	−0.474*	−0.180	−0.091	−0.950	−0.325
ϕ_{EERP}	1.139***	0.819***	0.637**	1.141***	−0.255	0.178	−0.186
ϕ_{OD}	−0.018	0.298	−0.137	−0.049	−0.157	−0.208	−0.031

Notes: The table presents the estimation results of the model (2), where the parameters for the risk factors and the contagion variables were allowed to change during the European debt crisis (after May 2010). The model is estimated in differences and using Newey-West standard errors with thirty lags. *, **, and *** denote the 10 percent, 5 percent, and 1 percent significance levels, respectively.

explained by the fact that the credit risk is typically very low in sovereign bonds compared with, e.g., corporate bonds, even though the perceived credit risk might have increased in recent years in some countries.

Second, liquidity risk as proxied by the bid-ask spread is typically more important after May 2010, and the same applies to the variable ITRXX, which proxies the risk appetite in the European bond markets. In fact, ITRXX is insignificant or only marginally significant in all but Germany prior to May 2010. Overall, then, the results clearly suggest that bond spreads became more sensitive to risk factors after May 2010.

As for the lagged yield spreads of the other countries, the results point to increasing interdependency after May 2010. In particular, the movements in Spanish, Italian, and Greek bond spreads after May 2010 have impacted more strongly other countries, suggesting that contagion effects became more important.

5. Conclusions

During the last five years or so, the European sovereign debt markets have experienced unprecedented turmoil. It is very important to understand which part of evolution of bond spreads is caused by expectations related to the changes in countries' economic fundamentals and underlying economic environment and which part is caused by the changes in the general risk appetite. If the increases in the bond spreads are caused by the increased credit risk, it is very likely that the yields are going to stay elevated for a very long time. In this case it is not enough to provide time and liquidity to these markets; the trust of the markets is gained only by improving the long-term sustainability of the government's fiscal position. It is also important to understand which actual policies have been successful in calming the stressed markets. In this paper we have focused on the impact of a wide range of policy announcements made during the latest financial crisis on the long-term sovereign bond yields of seven European countries. We examined these policy effects with an empirical model where we control the effect of credit and liquidity risks as well as general risk aversion and contagion between the countries.

We find that many policy decisions aimed at stabilizing the European debt crisis have had significant effects on the sovereign bond spreads. As expected, the decisions have caused a mixture of reactions in different countries. A decision that eases the pressure in one country may aggravate the situation in others, reflecting contagion but also the risk-sharing nature of some of the policy decisions. Quantitatively, the most significant effects are due to the announcement of the ECB's Securities Market Program, Outright Monetary Transactions, and ECB President Draghi's "whatever-it-takes-speech" in June 2012. Rather strong effects on bond spreads were also due to the decisions related to the European Financial Stability Facility, Greek debt restructuring, and the European Economic and Recovery Program. The decision on Greek debt restructuring led to a very strong decline of yield spreads in Greece, but at the same time it increased the perceived riskiness of French, Italian, and Irish government bonds. At the same time, all the decisions related to the new European economic governance have not been successful in reducing uncertainty in the countries whose sovereign debt markets have been under stress. Uncertainty related to fiscal sustainability was probably dominating the impact of those decisions that should improve the European fiscal landscape in the long run. This may also reflect the high political risk associated with these decisions and an unproven commitment of individual member states to collectively follow the rules.

As for the other risk factors, we find that macroeconomic news, which we have used as a proxy for credit risk, has played a somewhat more important role after May 2010, when the European debt crisis intensified. Overall, however, this factor is relatively unimportant for most of the countries in our study. At the same time, we have found relatively strong evidence that bond spreads became more sensitive to changes in risk appetite and liquidity risk, and also contagion effects strengthened after May 2010. Consistently with these, policies that were directly geared towards dispelling investors' fears on funding strains and on market illiquidity in the sovereign markets were apparently most efficient. The effectiveness of these measures shows that the European Monetary Union, as any monetary union, needs efficient backstop mechanisms that can be used in the event of crises.

Appendix 1. Macroeconomic News Variables

Table 5. Macroeconomic News Variables Used in Estimation

Indicator	Country						
	Germany	**France**	**Spain**	**Italy**	**Portugal**	**Ireland**	**Greece**
Budget Balance	X	X	X	X	X		
Current Account Balance	X	X	X	X	X	X	X
Trade Balance	X	X	X	X	X	X	
Government Spending	X						
General Government Debt				X			
GDP	X	X	X	X	X	X	X
Industrial Production	X	X	X	X	X	X	X
Unemployment	X	X	X	X	X	X	X
Consumer Confidence	X	X		X	X	X	
Business Confidence		X	X	X			
Economic Climate/Sentiment					X	X	
IFO Business Climate	X						
ZEW Survey Expectations	X						
PMI	X	X		X			

Notes: The table presents the sets of macroeconomic news variables that were used to construct an indicator *MNEWS* for each country. See the main text for further explanation.

Appendix 2. List of Policy Decisions

- May 25, 2007: ECB's amendment to the criteria for assets eligible as collateral for Eurosystem credit operations. (*ECBcrs*)
- August 22, 2007: ECB decided to conduct a supplementary liquidity-providing longer-term refinancing operation with a maturity of three months. (*ECBls*)
- September 6, 2007: ECB decided to conduct a supplementary liquidity-providing longer-term refinancing operation with a maturity of three months. (*ECBls*)
- March 28, 2008: ECB decided on supplementary six-month longer-term refinancing operations and continuation of the supplementary three-month longer-term refinancing operations. (*ECBls*)
- October 8, 2008: ECB decided that the weekly main refinancing operations will be carried out through a fixed-rate tender procedure with full allotment at the interest rate on the main refinancing operation. (*ECBls*)
- October 15, 2008: ECB decided on measures to further expand the collateral framework and enhance the provision of liquidity. (*ECBcrl*)
- November 26, 2008: ECB decided on changes to the temporary expansion of the eligibility of collateral. (*ECBcrs*) European economic recovery plan. (*EERP*)
- May 7, 2009: ECB decided to conduct liquidity-providing longer-term refinancing operations (LTROs) with a maturity of one year. (*ECBls*)
- May 27, 2009: New European financial supervisory framework. (*OD*)
- June 4, 2009: ECB decided on the Covered Bond Purchase Program. (*ECBcb*)
- April 8, 2010: ECB introduced graduated valuation haircuts for lower-rated assets in its collateral framework. (*ECBcrs*)
- April 12, 2010: €110 billion for Greece. (*SPdec*)
- May 3, 2010: ECB announced change in eligibility of debt instruments issued or guaranteed by the Greek government. (*ECBcrl*)
- May 10, 2010: €750 billion for European support package to secure stability the euro-area. (*SPdec*) ECB decided to

conduct interventions in the euro-area public and private debt securities markets (Securities Markets Program). (*ECBsmp*)

- September 29, 2010: New Economic Governance Package. (*OD*)
- October 28, 2010: The European Council agreed on the need to set up a permanent crisis-resolution mechanism. (*ESM*)
- November 21, 2010: Ireland requests financial support. (*SPreq*)
- November 29, 2010: Agreement of financial assistance program for Ireland (€85 billion). (*SPdeq*) Agreement on the key elements of the European Stability Mechanism. (*ESM*)
- December 16, 2010: The European Council agreed on limited amendment to the EU Treaty to underpin the permanent mechanism. (*ESM*)
- March 11, 2011: Pact for the euro was endorsed. (*OD*)
- March 21, 2011: Eurogroup+ agreed on the organizational and financial details of the ESM. (*ESM*)
- March 25, 2011: Heads of state finalize comprehensive package. (*OD*)
- April 8, 2011: Ministers acknowledged the Portuguese authorities' request for financial assistance. (*SPreq*)
- May 16, 2011: Agreement of financial assistance program to Portugal. (*SPdec*)
- June 20, 2011: Agreement to increase effective capacity and widen the mandate of the European Financial Stability Facility. (*EFSF*)
- July 7, 2011: ECB announces change in eligibility of debt instruments issued or guaranteed by the Portuguese government. (*ECBcrl*)
- July 21, 2011: Euro Zone Summit, second package for Greece (*SPdec*), and widening of the scope of EFSF/ESM. (*EFSF*)
- August 4, 2011: The Eurosystem decided to conduct a liquidity-providing supplementary longer-term refinancing operation with a maturity of approximately six months as a fixed-rate tender procedure with full allotment. (*ECBls*)
- October 6, 2011: ECB decided to conduct two longer-term refinancing operations—one with a maturity of approximately twelve months in October 2011, and another with a maturity of approximately thirteen months in December 2011. (*ECBls*)

ECB decided to launch a new Covered Bond Purchase Program in November 2011. (*ECBcb*)

- November 8, 2011: Enforcing budgetary discipline. (*OD*)
- November 26, 2011: Euro-area Finance Ministers agreed on the terms and conditions to leverage EFSF's capacity. (*EFSF*)
- December 8, 2011: ECB announced measures to support bank lending and money-market activity: two longer-term refinancing operations (LTROs) with a maturity of thirty-six months. (*ECBls*) ECB decided to increase collateral availability. (*ECBcrl*)
- December 19, 2011: EU member states support a substantial increase in the IMF's resources. (*OD*)
- February 2, 2012: Treaty establishing the European Stability Mechanism (*ESM*): New legal text of the ESM treaty. (*ESM*)
- February 20, 2012: New Greek package. (*SPdec*)
- February 28, 2012: ECB decided on the eligibility of Greek bonds used as collateral in Eurosystem monetary policy operations. (*ECBcrs*)
- March 2, 2012: Treaty on Stability, Coordination and Governance in the Economic and Monetary Union. (*OD*)
- March 8, 2012: ECB decided on the eligibility of bonds issued or guaranteed by the Greek government in Eurosystem credit operations. (*ECBcrl*)
- March 9, 2012: Private investors agreed to Greek debt restructuring. (*Drst*)
- March 30, 2012: The current overall ceiling for ESM/EFSF lending, as defined in the ESM Treaty, will be raised to €700 billion such that the ESM and the EFSF will be able to operate. (*ESM, EFSF*)
- June 22, 2012: ECB decided to take further measures to increase collateral availability for counterparties. (*ECBcrl*)
- June 25, 2012: The request of the Spanish government for financial assistance. (*SPreq*)
- June 27, 2012: The request of the Cypriot authorities for financial assistance. (*SPreq*)
- June 29, 2012: A single supervisory mechanism. (*OD*)
- July 9, 2012: The Eurogroup politically endorsed the ESM investment policy guideline. (*ESM*)

- July 20, 2012: ECB decided on the collateral eligibility of bonds issued or guaranteed by the Greek government. (*ECBcrs*) Package for Spain. (*SPdec*)
- July 26, 2012: Draghi speech in London. (*ECBdhi*)
- September 6, 2012: ECB made decisions on a number of technical features regarding the Eurosystem's outright transactions in secondary sovereign bond markets. (*ECBomt*) ECB decided on additional measures to preserve collateral availability for counterparties. (*ECBcrl*)
- November 27, 2012: Relaxing of financial/economic conditions for Greece. (*SPrelax*)
- December 14, 2012: The European Council agreed on a roadmap for the completion of the Economic and Monetary Union. (*OD*)
- December 19, 2012: ECB announced change in eligibility of debt instruments issued or guaranteed by the Greek government. (*ECBcrl*)
- March 16, 2013: Relaxing financial/economic conditions for Ireland and Portugal. (*SPrelax*)
- March 22, 2013: ECB announced changes to the use as collateral of certain uncovered government-guaranteed bank bonds. (*ECBcrs*)
- March 25, 2013: Support package for Cyprus. (*SPdec*)
- May 2, 2013: ECB announced change in eligibility of marketable debt instruments issued or guaranteed by the Cypriot government. (*ECBcrl*)
- June 28, 2013: ECB decided on the eligibility of marketable debt instruments issued or guaranteed by the Republic of Cyprus. (*ECBcrs*)
- July 5, 2013: ECB announced change in eligibility of marketable debt instruments issued or guaranteed by the Cypriot government. (*ECBcrl*)

References

Aßmann, C., and J. Boysen-Hogrefe. 2012. "Determinants of Government Bond Spreads in the Euro Area: In Good Times as in Bad." *Empirica* 39 (3): 341–56.

Andersen, T., T. Bollerslev, F. Diebold, and C. Vega. 2003. "Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange." *American Economic Review* 93 (1): 38–62.

Arghyrou, M., and A. Kontonikas. 2012. "The EMU Sovereign-Debt Crisis: Fundamentals, Expectations and Contagion." *Journal of International Financial Markets, Institutions and Money* 22 (4): 658–77.

Arghyrou, M., and J. Tsoukalas. 2011. "The Greek Debt Crisis: Likely Causes, Mechanics and Outcomes." *The World Economy* 34 (2): 173–91.

Attinasi, M.-G., C. Checherita, and C. Nickel. 2009. "What Explains the Surge in Euro-Area Sovereign Spreads during the Financial Crisis of 2007-09?" ECB Working Paper No. 1131.

Barbosa, L., and S. Costa. 2010. "Determinants of Sovereign Bond Yield Spreads in the Euro Area in the Context of the Economic and Financial Crisis." *Economic Bulletin* (Banco de Portugal) (Autumn): 131–50.

Barrios, S., P. Iversen, M. Lewandowska, and R. Setzer. 2009. "Determinants of Intra-Euro Area Government Bond Spreads during the Financial Crisis." European Economy Economic Paper No. 388, Directorate General Economic and Monetary Affairs, European Commission.

Beber, A., M. Brandt, and K. Kavajecz. 2009. "Flight-to-Quality or Flight-to-Liquidity? Evidence from the Euro-Area Bond Market." *Review of Financial Studies* 22 (3): 925–57.

Bernoth, K., and B. Erdogan. 2012. "Sovereign Bond Yield Spreads: A Time-Varying Coefficient Approach." *Journal of International Money and Finance* 31 (3): 639–56.

Bernoth, K., J. von Hagen, and L. Schuknecht. 2012. "Sovereign Risk Premiums in the European Government Bond Market." *Journal of International Money and Finance* 31 (5): 975–95.

Borgy, V., T. Laubach, J.-S. Mésonnier, and J.-P. Renne. 2011. "Fiscal Sustainability, Default Risk and Euro Area Sovereign Bond Spreads." Working Paper No. 350, Banque de France.

Caceres, C., V. Guzzo, and M. Segoviano. 2010. "Sovereign Spreads: Global Risk Aversion, Contagion or Fundamentals?" IMF Working Paper No. 10/120.

Claeys, P., and B. Vašíček. 2012. "Measuring Sovereign Bond Spillover in Europe and the Impact of Rating News." Working Paper No. 2012/07, Czech National Bank, Research Department.

Eser, F., and B. Schwaab. 2013. "Assessing Asset Purchases within the ECB's Securities Markets Programme." ECB Working Paper No. 1587.

Favero, C., M. Pagano, and E.-L. von Thadden. 2010. "How Does Liquidity Affect Government Bond Yields?" *Journal of Financial and Quantitative Analysis* 45 (1): 107–34.

Fontana, A., and M. Scheicher. 2010. "An Analysis of Euro Area Sovereign CDS and their Relation with Government Bonds." ECB Working Paper No. 1271.

Gagnon, J., M. Raskin, J. Remache, and B. Sack. 2011. "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases." *International Journal of Central Banking* 7 (1): 3–43.

Gapen, M., D. Gray, C. Lim, and Y. Xiao. 2008. "Measuring and Analyzing Sovereign Risk with Contingent Claims." *IMF Staff Papers* 55 (1): 109–148.

Gerlach, S., A. Schulz, and G. Wolff. 2010. "Banking and Sovereign Risk in the Euro Area." CEPR Discussion Paper No. 7833.

Gómez-Puig, M. 2009. "Systemic and Idiosyncratic Risk in EU-15 Sovereign Yield Spreads after Seven Years of Monetary Union." *European Financial Management* 15 (5): 971–1000.

Hamilton, J., and C. Wu. 2012. "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment." *Journal of Money, Credit and Banking* 44 (s1): 3–46.

Haugh, D., P. Ollivaud, and D. Turner. 2009. "What Drives Sovereign Risk Premiums? An Analysis of Recent Evidence from the Euro Area." OECD Economics Department Working Paper No. 718.

Hollo, D., M. Kremer, and M. Lo Duca. 2012. "CISS — A Composite Indicator of Systemic Stress in the Financial System." ECB Working Paper No. 1426.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2011. "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy." *Brooking Papers on Economic Activity* (Fall): 215–87.

———. 2013. "The Ins and Outs of LSAPs." In *Global Dimensions of Unconventional Monetary Policy*, 57–111. Proceedings of an annual Economic Policy Symposium sponsored by the Federal Reserve Bank of Kansas City, held in Jackson Hole, Wyoming, August 22–24.

Manganelli, S., and G. Wolswijk. 2009. “What Drives Spreads in the Euro Area Government Bond Market?” *Economic Policy* 24 (58): 191–240.

Merton, R. 1974. “On the Pricing of Corporate Debt: The Risk Structure of Interest Rates.” *Journal of Finance* 29 (2): 449–70.

Oliveira, L., J. Curto, and J. Nunes. 2012. “The Determinants of Sovereign Credit Spread Changes in the Euro-Zone.” *Journal of International Financial Markets, Institutions and Money* 22 (2): 278–304.

Palladini, G., and R. Portes. 2011. “Sovereign CDS and Bond Pricing Dynamics in the Euro-area.” NBER Working Paper No. 17586.

Pozzi, L., and G. Wolswijk. 2012. “The Time-Varying Integration of Euro Area Government Bond Markets.” *European Economic Review* 56 (1): 35–53.

Rai, A. M. 2013. “The Impact of Policy Initiatives on Credit Spreads during the 2007–09 Financial Crisis.” *International Journal of Central Banking* 9 (1): 45–104.

Sgherri, S., and E. Zoli. 2009. “Euro Area Sovereign Risk during the Crisis.” IMF Working Paper No. 222.

Schwarz, K. 2010. “Mind the Gap: Disentangling Credit and Liquidity in Risk Spreads.” Working Paper, Wharton School, University of Pennsylvania.

von Hagen, J., L. Schuknecht, and G. Wolswijk. 2011. “Government Bond Risk Premiums in the EU Revisited: The Impact of the Financial Crisis.” *European Journal of Political Economy* 27 (1): 36–43.