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BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM
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To: Research Directors

From: Matthew M. Luecke

Subject: Supporting Documents for DSGE Models Update

The attached documents support the update on the projections of the DSGE models.

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System DSGE Project

Research Directors Drafts

EDO (Board), FRBNY (New York), Prism (FRB Philadelphia)

September 5, 2014

The Current Outlook in EDO: September FOMC Meeting (Class II – Restricted FR)

Tobias Cwik*

September 5, 2014

1 The EDO Forecast from 2014 to 2016

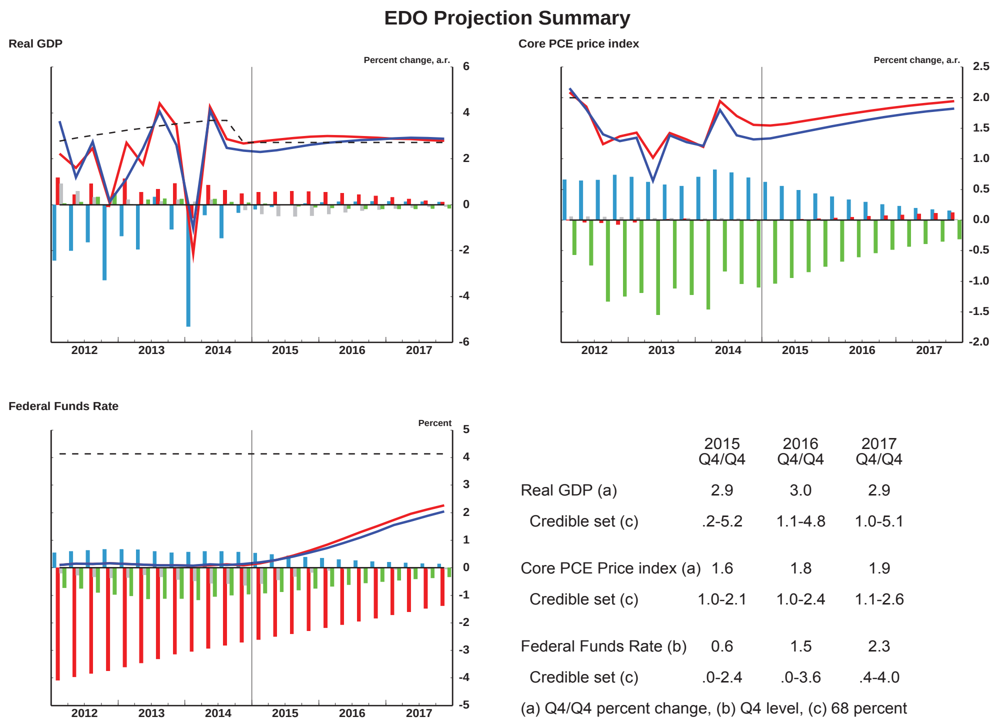
Given recent data (including expectations for the federal funds rate), EDO projects on trend average real GDP growth until the end of 2015 while unemployment remains around 6.5 percent through 2016 (Figures 1 and 3).[1] This subdued pace of real activity is accompanied by below-target inflation, which slowly rises from a low of 1.6 percent at 2014:Q4 to 1.9 percent by 2016.

This baseline is heavily shaped by the model's interpretation of the low level of interest rates. In particular, low interest rates over the projection reflect, according to the implementation used in the projection, both the drag on interest rates imparted by past and prospective weakness in activity and some degree of monetary accommodation, with the first factor the more important, largely by assumption (as fluctuations in risk premiums are the dominant factor in accounting for fluctuations in expected interest rates over history, and hence are also assumed to be important over the projection period). Because market expectations for low interest rates owe (in the model) importantly to weak expected demand, the model projects that the aggregate risk premium will rise to its early 2012 levels, lowering GDP growth and boosting unemployment above its long-run level. But the negative impact of the rise in the aggregate risk premium is partly offset by expected unusually accommodative monetary policy in 2014. In addition, lower-than-expected labor productivity and surprisingly strong inflation since last year have led the model to infer a deterioration in aggregate supply conditions, which modestly reduces GDP growth early in the projection.

*Tobias Cwik (tobias.cwik@frb.gov) is affiliated with the Division of Research and Statistics of the Federal Reserve Board. Sections 2 and 3 contain background material on the EDO model, as in previous rounds. These sections were co-written with Hess Chung and Jean-Philippe Laforte.

[1]The baseline forecast for EDO is conditioned on the staff's preliminary September 2014 Tealbook projection through 2014:Q3 and market expectations that the federal funds rate will remain at its effective lower bound through the second quarter of 2015 (as indicated by OIS market prices). We do not impose an unemployment or inflation threshold on the monetary policy rule.
The model's static structural parameters have been re-estimated using data through 2014:Q3. In particular, the new estimates incorporate the latest comprehensive revision to NIPA data. For estimation, the observable corresponding to the model's concept of investment excludes spending on intellectual property products.

Figure 1: Recent History and Forecasts



	2015 Q4/Q4	2016 Q4/Q4	2017 Q4/Q4
Real GDP (a)	2.9	3.0	2.9
Credible set (c)	.2-5.2	1.1-4.8	1.0-5.1
Core PCE Price index (a)	1.6	1.8	1.9
Credible set (c)	1.0-2.1	1.0-2.4	1.1-2.6
Federal Funds Rate (b)	0.6	1.5	2.3
Credible set (c)	.0-2.4	.0-3.6	.4-4.0

(a) Q4/Q4 percent change, (b) Q4 level, (c) 68 percent

Red, solid line -- Data (through 2014:Q3) and projections; Blue, solid line -- Previous projection (June, 2014, as of 2014:Q2); Black, dashed line -- Steady-state or trend values
Contributions (bars): Red -- Financial; Blue -- Technology; Silver -- Monetary policy; Green -- Other

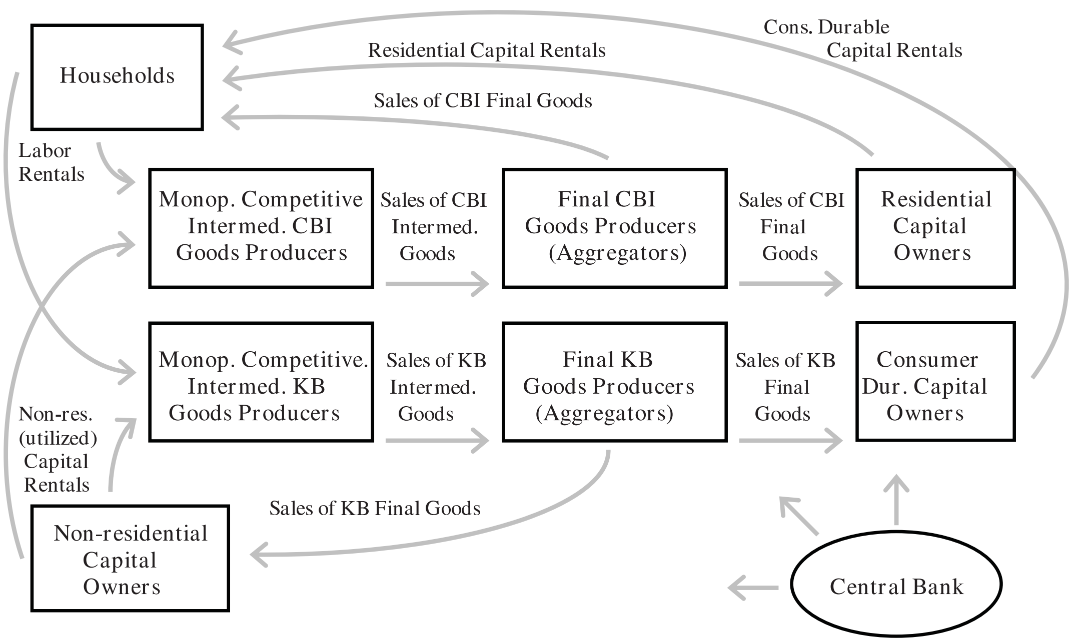
Inflation is held below target by a combination of weak aggregate demand and muted pressure on wages in the labor market. Indeed, the unemployment rate rises through early 2015, driven largely by the aforementioned weak demand conditions. By the end of the forecast, however, a substantial portion of the elevated unemployment rate is accounted for the stickiness in wages and prices in EDO, which prevents the real wage from falling sufficiently to bring down unemployment; indeed, EDO estimates that the real wage must decline notably to clear the labor market.[2]

[2]As discussed below, unemployment enters the EDO model through a new-Keynesian wage Phillips curve, without much specificity regarding structural labor-market features. As such, the primary role of unemployment is as a gauge of the degree to which real-wage adjustment impedes labor market clearing, and anomalously persistent and elevated rates of unemployment lead EDO to detect a decline in the real wage needed to clear the labor market. While most of the runup in unemployment since 2007 is driven by weak demand (in EDO), the model identifies a component of the increase in unemployment as due to a decline in the market-clearing real wage. Finally, as noted in the model description below, such a decline is implemented in the model by a shift in labor supply.

2 An Overview of Key Model Features

Figure 2 provides a graphical overview of the model. While similar to most related models, EDO has a more detailed description of production and expenditure than most other models.[3]

Figure 2: Model Overview



Specifically, the model possesses two final good sectors in order to capture key long-run growth facts and to differentiate between the cyclical properties of different categories of durable expenditure (e.g., housing, consumer durables, and nonresidential investment). For example, technological progress has been faster in the production of business capital and consumer durables (such as computers and electronics).

The disaggregation of production (aggregate supply) leads naturally to some disaggregation of expenditures (aggregate demand). We move beyond the typical model with just two categories of (private domestic) demand (consumption and investment) and distinguish between four categories of private demand: consumer non-durable goods and non-housing services, consumer durable goods, residential investment, and non-residential investment. The boxes surrounding the producers in the

[3] Chung, Kiley, and Laforte (2011) provide much more detail regarding the model specification, estimated parameters, and model propeties.

figure illustrate how we structure the sources of each demand category. Consumer non-durable goods and services are sold directly to households; consumer durable goods, residential capital goods, and non-residential capital goods are intermediated through capital-goods intermediaries (owned by the households), who then rent these capital stocks to households. Consumer non-durable goods and services and residential capital goods are purchased (by households and residential capital goods owners, respectively) from the first of economy's two final goods producing sectors, while consumer durable goods and non-residential capital goods are purchased (by consumer durable and residential capital goods owners, respectively) from the second sector. In addition to consuming the non-durable goods and services that they purchase, households supply labor to the intermediate goods-producing firms in both sectors of the economy.

This remainder of this section provides an overview of the key properties of the model. In particular, the model has five key features:

- A new-Keynesian structure for price and wage dynamics. Unemployment measures the difference between the amount workers are willing to be employed and firms' employment demand. As a result, unemployment is an indicator of wage, and hence price, pressures, as in Gali (2010).
- Production of goods and services occurs in two sectors, with differential rates of technological progress across sectors. In particular, productivity growth in the investment and consumer durable goods sector exceeds that in the production of other goods and services, helping the model match facts regarding long-run growth and relative price movements.
- A disaggregated specification of household preferences and firm production processes that leads to separate modeling of nondurables and services consumption, durables consumption, residential investment, and business investment.
- Risk premia associated with different investment decisions play a central role in the model. These include A) an aggregate risk-premium, or natural rate of interest, shock driving a wedge between the short-term policy rate and the interest rate facing private decisionmakers (as in Smets and Wouters (2007)) and B) fluctuations in the discount factor/risk premia facing the intermediaries financing household (residential and consumer durable) and business investment.

2.1 Two-sector production structure

It is well known (e.g., Edge, Kiley, and Laforte (2008)) that real outlays for business investment and consumer durables have substantially outpaced those on other goods and services, while the prices of these goods (relative to others) has fallen. For example, real outlays on consumer durables have far outpaced those on other consumption, while prices for consumer durables have been flat and those for other consumption have risen substantially; as a result, the ratio of nominal outlays in the two categories has been much more stable, although consumer durable outlays plummeted in the Great Recession. Many models fail to account for this fact.

EDO accounts for this development by assuming that business investment and consumer durables are produced in one sector and other goods and services in another sector. Specifically, production by firm j in each sector s (where s equals kb for the sector producing business investment and consumer durables sector and cbi for the sector producing other goods and services) is governed by a Cobb-Douglas production function with sector-specific technologies:

$$X_t^s(j) \ = \left(Z_t^m Z_t^s L_t^s(j)\right)^{1-\alpha} \left(K_t^{u,nr,s}(j)\right)^{\alpha}, \text{ for } s = cbi, kb. \tag{1}$$

In 1, Z^m represents (labor-augmenting) aggregate technology, while Z^s represents (labor-augmenting) sector-specific technology; we assume that sector-specific technological change affects the business investment and consumer durables sector only; L^s is labor input and $K^{u,nr,s}$ is capital input (that is, utilized *non-residential business* capital (and hence the nr and u terms in the superscript). Growth in this sector-specific technology accounts for the long-run trends, while high-frequency fluctuations allow the possibility that investment-specific technological change is a source of business cycle fluctuations, as in Fisher (2006).

2.2 The structure of demand

EDO differentiates between several categories of expenditure. Specifically, business investment spending determines non-residential capital used in production, and households value consumer nondurables goods and services, consumer durable goods, and residential capital (e.g., housing). Differentiation across these categories is important, as fluctuations in these categories of expenditure can differ notably, with the cycles in housing and business investment, for example, occurring at different points over the last three decades.

Valuations of these goods and services, in terms of household utility, is given by the following utility function:

$$\begin{aligned}\mathcal{E}_0\sum_{t=0}^{\infty}\beta^t\Big\{&\varsigma^{cnn}\ln(E_t^{cnn}(i)-hE_{t-1}^{cnn}(i))+\varsigma^{cd}\ln(K_t^{cd}(i))\\ &+\varsigma^{r}\ln(K_t^{r}(i)) \ -\varsigma^{l}\frac{(L_t^{cbi}(i)+L_t^{kb}(i))^{1+\nu}}{1+\nu}\Big\},\end{aligned} \tag{2}$$

where E^{cnn} represents expenditures on consumption of nondurable goods and services, K^{cd} and K^r represent the stocks of consumer durables and residential capital (housing), $L^{cbi} + L^{kb}$ represents the sum of labor supplied to each productive sector (with hours worked causing disutility), and the remaining terms represent parameters (such as the discount factor, relative value in utility of each service flow, and the elasticity of labor supply).

By modeling preferences over these disaggregated categories of expenditure, EDO attempts to account for the disparate forces driving consumption of nondurables and durables, residential investment, and business investment – thereby speaking to issues such as the surge in business investment in the second half of the 1990s or the housing cycle the early 2000s recession and the most recent downturn. Many other models do not distinguish between developments across these categories of spending.

2.3 Risk premia, financial shocks, and economic fluctuations

The structure of the EDO model implies that households value durable stocks according to their expected returns, including any expected service flows, and according to their risk characteristics, with a premium on assets which have high expected returns in adverse states of the world. However, the behaviour of models such as EDO is conventionally characterized under the assumption that this second component is negligible. In the absence of risk adjustment, the model would then imply that households adjust their portfolios until expected returns on all assets are equal.

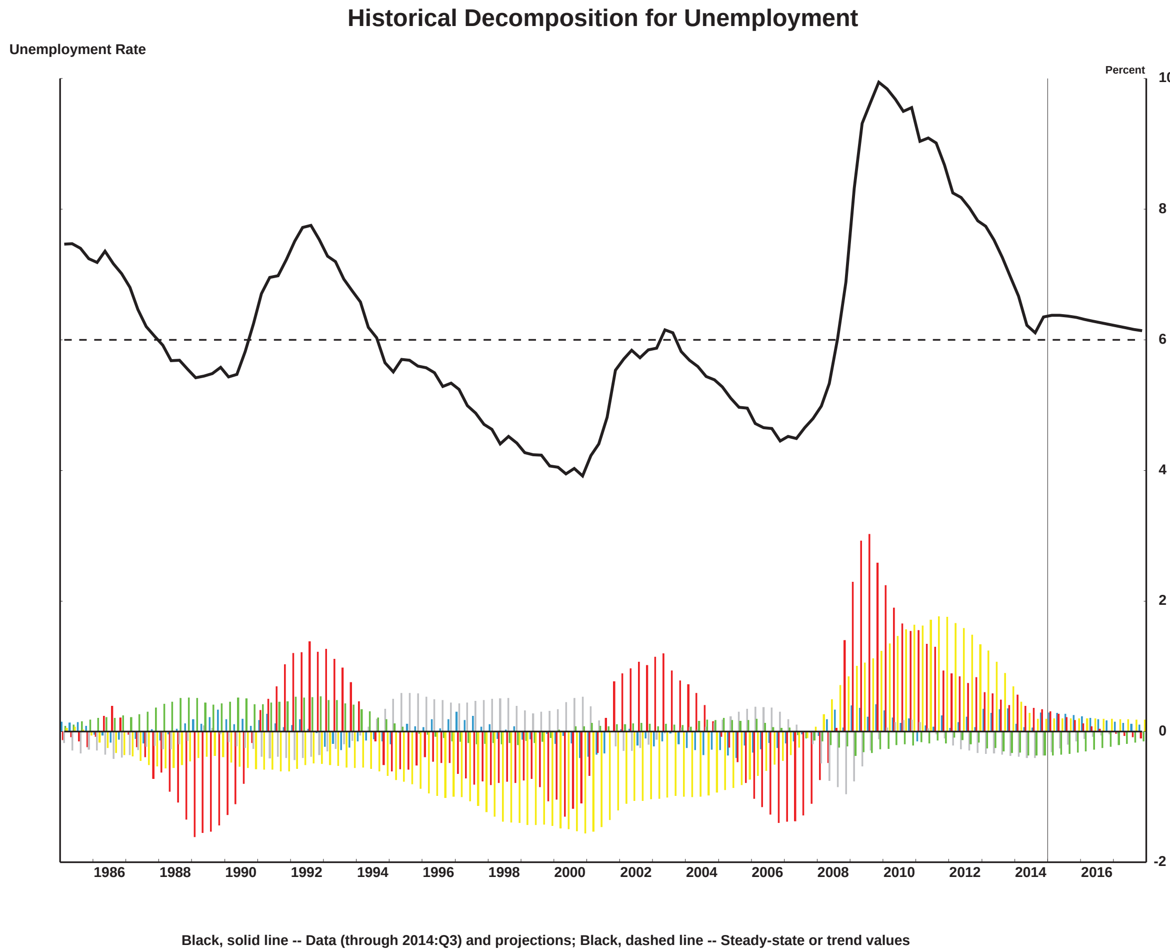
Empirically, however, this risk adjustment may not be negligible and, moreover, there may be a variety of factors, not explicitly modelled in EDO, which limit the ability of households to arbitrage away expected return differentials across different assets. To account for this possibility, EDO features several exogenous shocks to the rates of return required by the household to hold the assets in question. Following such a shock – an increase in the premium on a given asset, for example– households will wish to alter their portfolio composition to favor the affected asset, leading to changes in the prices of all assets and, ultimately, to changes in the expected path of production underlying these claims.

The "sector-specific" risk shocks affect the composition of spending more than the path of GDP itself. This occurs because a shock to these premia leads to sizable substitution across residential, consumer durable, and business investment; for example, an increase in the risk premia on residential investment leads households to shift away from residential investment and towards other types of productive investment. Consequently, it is intuitive that a large fraction of the non-cyclical, or idiosyncratic, component of investment flows to physical stocks will be accounted for by movements in the associated premia.

Shocks to the required rate of return on the nominal risk-free asset play an especially large role in EDO. Following an increase in the premium, in the absence of nominal rigidities, the households' desire for higher real holdings of the risk-free asset would be satisfied entirely by a fall in prices, i.e., the premium is a shock to the natural rate of interest. Given nominal rigidities, however, the desire for higher risk-free savings must be off-set, in part, through a fall in real income, a decline which is distributed across all spending components. Because this response is capable of generating comovement across spending categories, the model naturally exploits such shocks to explain the business cycle. Reflecting this role, we denote this shock as the "aggregate risk-premium".

Movements in financial markets and economic activity in recent years have made clear the role that frictions in financial markets play in economic fluctuations. This role was apparent much earlier, motivating a large body of research (e.g.,Bernanke, Gertler, and Gilchrist (1999)). While the range of frameworks used to incorporate such frictions has varied across researchers studying different questions, a common theme is that imperfections in financial markets – for example, related to imperfect information on the outlook for investment projects or earnings of borrowers – drives a wedge between the cost of riskless funds and the cost of funds facing households and firms. Much of the literature on financial frictions has worked to develop frameworks in which risk premia fluctuate for endogenous reasons (e.g., because of movements in the net worth of borrowers). Because the risk-premium shocks induces a wedge between the short-term nominal risk-free rate and the rate of return on the affected risky rates, these shocks may thus also be interpreted as a reflection of financial frictions not explicitly modelled in EDO. The sector-specific risk premia in EDO enter the model in much the same way as does the exogenous component of risk premia in models with some endogenous mechanism (such as the financial accelerator framework used Boivin, Kiley, and Mishkin (2010)), and the exogenous component is quantitatively the most significant one in that research.[4]

Figure 3: Unemployment Fluctuations in the EDO model



2.4 Unemployment Fluctuations in the EDO model

This version of the EDO model assumes that labor input consists of both employment and hours per worker. Workers differ in the disutility they associate with employment. Moreover, the labor market

[4]Specifically, the risk premia enter EDO to a first-order (log)linear approximation in the same way as in the cited research if the parameter on net worth in the equation determining the borrowers cost of funds is set to zero; in practice, this parameter is often fairly small in financial accelerator models.

is characterized by monopolistic competition. As a result, unemployment arises in equilibrium – some workers are willing to be employed at the prevailing wage rate, but cannot find employment because firms are unwilling to hire additonal workers at the prevailing wage.

As emphasized by Gali (2010), this framework for unemployment is simple and implies that the unemployment rate reflects wage pressures: When the unemployment rate is unusually high, the prevailing wage rate exceeds the marginal rate of subsitution between leisure and consumption, implying that workers would prefer to work more.

In addition, in our environment, nominal wage adjustment is sticky, and this slow adjustment of wages implies that the economy can experience sizable swings in unemployment with only slow wage adjustment. Our specific implementation of the wage adjustment process yields a relatively standard New-Keynesian wage Phillips curve. The presence of both price and wage rigidities implies that stabilization of inflation is not, in general, the best possible policy objective (although a primary role for price stability in policy objectives remains).

While the specific model on unemployment is suitable for discussions of the links between unemployment and wage/price inflation, it leaves out many features of labor market dynamics. Most notably, it does not consider separations, hires, and vacancies, and is hence not amenable to analysis of issues related to the Beveridge curve.

As emphasized above, the rise in unemployment during the Great Recession primarily reflected, according to the EDO model, the weak demand that arose from elevated risk premiums that depressed spending, as illustrated by the red bars in figure 3.

Indeed, these demand factors explain the overwhelming share of cyclical movements in unemployment over the past two-and-a-half decades, as is also apparent in figure 3. Other factors are important for some other periods. For example, monetary policymakers lowered the federal funds rate rapidly over the course of 2008, somewhat in advance of the rise in unemployment and decline in inflation that followed. As illustrated by the silver bars in figure 3, these policy moves mitigated the rise in unemployment somewhat over 2009; however, monetary policy efforts provided less stimulus, according to EDO, over 2010 and 2011 – when the federal funds rate was constrained from falling further. (As in many other DSGE models, EDO does not include economic mechanisms through which quantitative easing provides stimulus to aggregate demand).

The contribution of supply shocks – most notably labor supply shocks – is also estimated to contribute importantly to the low-frequency movements in unemployment, as shown by the yellow bars in figure 3. Specifically, favorable supply developments in the labor market are estimated to have placed downward pressure on unemployment during the second half of the 1990s; these developments have reversed, and some of the currently elevated rate of unemployment is, according to EDO, attributable to adverse labor market supply developments. As discussed previously, these developments are simply exogenous within EDO and are not informed by data on a range of labor market developments (such as gross worker flows and vacancies).

2.5 New-Keynesian Price and Wage Phillips Curves

As in most of the related literature, nominal prices and wages are both "sticky" in EDO. This friction implies that nominal disturbances – that is, changes in monetary policy – have effects on real economic activity. In addition, the presence of both price and wage rigidities implies that stabilization of inflation is not, in general, the best possible policy objective (although a primary role for price stability in policy objectives remains).

Given the widespread use of the New-Keynesian Phillips curve, it is perhaps easiest to consider the form of the price and wage Phillips curves in EDO at the estimated parameters. The price Phillips curve (governing price adjustment in both productive sectors) has the form:

$$\pi_t^{p,s} = 0.22\pi_{t-1}^{p,s} + 0.76E_t\pi_{t+1}^{p,s} + .017mc_t^s + \theta_t^s \tag{3}$$

where mc is marginal cost and θ is a markup shock. As the parameters indicate, inflation is primarily forward-looking in EDO.

The wage (w) Phillips curve for each sector has the form:

$$\triangle w_t^s = 0.01\triangle w_{t-1}^s + 0.95E_t\triangle w_{t+1}^s + .012\left(mrs_t^{c,l} - w_t^s\right) + \theta_t^w + adj.\,costs. \tag{4}$$

where mrs represents the marginal rate of substitution between consumption and leisure. Wages are primarily forward looking and relatively insensitive to the gap between households' valuation of time spent working and the wage.

The middle panel of figure 1 presents the decomposition of inflation fluctuations into the exogenous disturbances that enter the EDO model. As can be seen, aggregate demand fluctuations, including aggregate risk premiums and monetary policy surprises, contribute little to the fluctuations in inflation according to the model. This is not surprising: In modern DSGE models, transitory demand disturbances do not lead to an unmooring of inflation (so long as monetary policy responds systematically to inflation and remains committed to price stability). In the short run, inflation fluctuations primarily reflect transitory price and wage shocks, or markup shocks in the language of EDO. Technological developments can also exert persistent pressure on costs, most notably during and following the strong productivity performance of the second half of the 1990s which is estimated to have lowered marginal costs and inflation through the early 2000s. More recently, disappointing labor productivity readings over the course of 2011 have led the model to infer sizeable negative technology shocks in both sectors, contributing noticeably to inflationary pressure over that period (as illustrated by the blue bars in figure 1),

2.6 Monetary Authority and A Long-term Interest Rate

We now turn to the last agent in our model, the monetary authority. It sets monetary policy in accordance with an Taylor-type interest-rate feedback rule. Policymakers smoothly adjust the actual interest rate R_t to its target level $\bar{R}_t$

$$R_t = (R_{t-1})^{\rho^r} (\bar{R}_t)^{1-\rho^r} \exp[\epsilon_t^r], \tag{5}$$

where the parameter ρ^r reflects the degree of interest rate smoothing, while ϵ_t^r represents a monetary policy shock. The central bank's target nominal interest rate, $\bar{R}_t$ depends the deviation of output from the level consistent with current technologies and "normal" (steady-state) utilization of capital and labor ($\tilde{X}^{pf}$, the "production function" output gap) Consumer price inflation also enters the target. The target equation is:

$$\bar{R}_t = \left(\tilde{X}_t^{pf}\right)^{r^y} \left(\frac{\Pi_t^c}{\Pi_*^c}\right)^{r^\pi} R_*. \tag{6}$$

In equation (6), R_* denotes the economy's steady-state nominal interest rate, and ϕ^y and ϕ^π denote the weights in the feedback rule. Consumer price inflation, Π_t^c, is the weighted average of inflation in the nominal prices of the goods produced in each sector, $\Pi_t^{p,cbi}$ and $\Pi_t^{p,kb}$:

$$\Pi_t^c = (\Pi_t^{p,cbi})^{1-w_{cd}} (\Pi_t^{p,kb})^{w_{cd}}. \tag{7}$$

The parameter w^{cd} is the share of the durable goods in nominal consumption expenditures.

The model also includes a long-term interest rate (RL_t), which is governed by the expectations hypothesis subject to an exogenous term premia shock:

$$RL_t = \mathcal{E}_t \left[\Pi_{\tau=0}^N R_\tau\right] \cdot \Upsilon_t. \tag{8}$$

where Υ is the exogenous term premium, governed by

$$Ln(\Upsilon_t) = \left(1 - \rho^\Upsilon\right) Ln(\Upsilon_*) + \rho^\Upsilon Ln(\Upsilon_{t-1}) + \epsilon_t^\Upsilon. \tag{9}$$

In this version of EDO, the long-term interest rate plays no allocative role; nonetheless, the term structure contains information on economic developments useful for forecasting (e.g., Edge, Kiley, and Laforte (2010)) and hence RL is included in the model and its estimation.

2.7 Summary of Model Specification

Our brief presentation of the model highlights several points. First, although our model considers production and expenditure decisions in a bit more detail, it shares many similar features with other DSGE models in the literature, such as imperfect competition, nominal price and wage rigidities, and real frictions like adjustment costs and habit-persistence. The rich specification of structural shocks (to aggregate and investment-specific productivity, aggregate and sector-specific risk premiums, and mark-ups) and adjustment costs allows our model to be brought to the data with some chance of finding empirical validation.

Within EDO, fluctuations in all economic variables are driven by thirteen structural shocks. It is most convenient to summarize these shocks into five broad categories:

- Permanent technology shocks: This category consists of shocks to aggregate and investment-specific (or fast-growing sector) technology.

- A labor supply shock: This shock affects the willingness of to supply labor. As was apparent in our earlier description of the unemployment rate and in the presentation of the structural drivers below, this shock captures very persistent movements in unemployment that the model judges are not indicative of wage pressures. While EDO labels such movements labor supply shocks, an alternative interpretation would descrbie these as movements in unemployment that reflect persistent strucutral features not otherwise captured by the model.

- Financial, or intertemporal, shocks: This category consists of shocks to risk premia. In EDO, variation in risk premia – both the premium households' receive relative to the federal funds rate on nominal bond holdings and the additional variation in discount rates applied to the investment decisions of capital intermediaries – are purely exogenous. Nonetheless, the specification captures aspects of related models with more explicit financial sectors (e.g., Bernanke, Gertler, and Gilchrist (1999)), as we discuss in our presentation of the model's properties below.

- Markup shocks: This category includes the price and wage markup shocks.

- Other demand shocks: This category includes the shock to autonomous demand and a monetary policy shock.

3 Estimation: Data and Properties

3.1 Data

The empirical implementation of the model takes a log-linear approximation to the first-order conditions and constraints that describe the economy's equilibrium, casts this resulting system in its state-space representation for the set of (in our case 13) observable variables, uses the Kalman filter to evaluate the likelihood of the observed variables, and forms the posterior distribution of the parameters of interest by combining the likelihood function with a joint density characterizing some prior beliefs. Since we do not have a closed-form solution of the posterior, we rely on Markov-Chain Monte Carlo (MCMC) methods.

The model is estimated using 13 data series over the sample period from 1984:Q4 to 2011:Q4. The series are:

1. The civilian unemployment rate (U);
2. The growth rate of real gross domestic product (ΔGDP);
3. The growth rate of real consumption expenditure on non-durables and services (ΔC);
4. The growth rate of real consumption expenditure on durables (ΔCD);
5. The growth rate of real residential investment expenditure (ΔRes);
6. The growth rate of real business investment expenditure (ΔI);

7. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure (PCE) price index ($\Delta P_{C,total}$);
8. Consumer price inflation, as measured by the growth rate of the PCE price index excluding food and energy prices ($\Delta P_{C,core}$);
9. Inflation for consumer durable goods, as measured by the growth rate of the PCE price index for durable goods (ΔP_{cd});
10. Hours, which equals hours of all persons in the non-farm business sector from the Bureau of Labor Statistics (H);[5]
11. The growth rate of real wages, as given by compensation per hour in the non-farm business sector from the Bureau of Labor Statistics divided by the GDP price index (ΔRW);
12. The federal funds rate (R).
13. The yield on the 2-yr. U.S. Treasury security (RL).

Our implementation adds measurement error processes to the likelihood implied by the model for all of the observed series used in estimation except the short-term nominal interest rate series.

3.2 Variance Decompositions and impulse responses

We provide detailed variance decompositions and impulse response in Chung, Kiley, and Laforte (2011), and only highlight the key results here.

Volatility in aggregate GDP growth is accounted for primarily by the technology shocks in each sector, although the economy-wide risk premium shock contributes non-negligibly at short horizons.

Volatility in the unemployment rate is accounted for primarily by the economy-wide risk premium and business investment risk premium shocks at horizons between one and sixteen quarters. Technology shocks in each sector contribute very little, while the labor supply shock contributes quite a bit a low frequencies. The large role for risk premia shocks in the forecast error decomposition at business cycle horizons illustrates the importance of this type of "demand" shock for volatility in the labor market. This result is notable, as the unemployment rate is the series most like a "gap" variable in the model – that is, the unemployment rate shows persistent cyclical fluctuations about its long-run value.

Volatility in core inflation is accounted for primarily by the markup shocks.

Volatility in the federal funds rate is accounted for primarily by the economywide risk premium (except in the very near term, when the monetary policy shock is important).

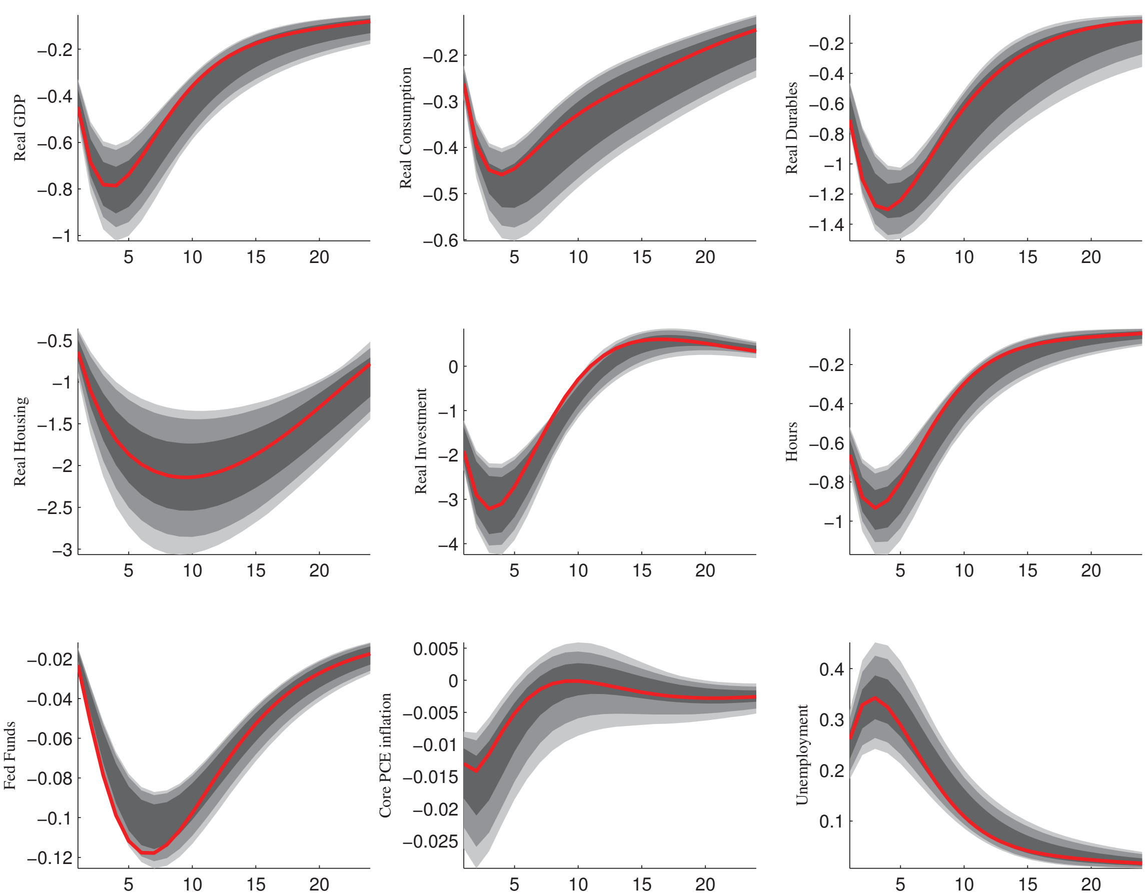
Volatility in expenditures on consumer non-durables and non-housing services is, in the near horizon, accounted for predominantly by economy-wide risk-premia shocks. In the far horizon, volatility is accounted for primarily by capital-specific and economy-wide technology shocks.

Volatilities in expenditures on consumer durables, residential investment, and non-residential investment are, in the near horizon, accounted for predominantly by their own sector

[5]We remove a low-frequency trend from hours. We first pad the historical series by appending 40 quarterly observations which approach the most recent 40-quarter moving average of the data at a rate of 0.05 percent per quarter. We then extract a trend from this padded series via the Hodrick-Prescott filter with a smoothing parameter of 6400; our model is not designed to capture low frequency trends in population growth or labor force participation.

specific risk-premium shocks. At farther horizons, their volatilities are accounted for by technology shocks.

Figure 4: Impulse Response to a One Standard Deviation Shock to the Aggregate Risk Premium.

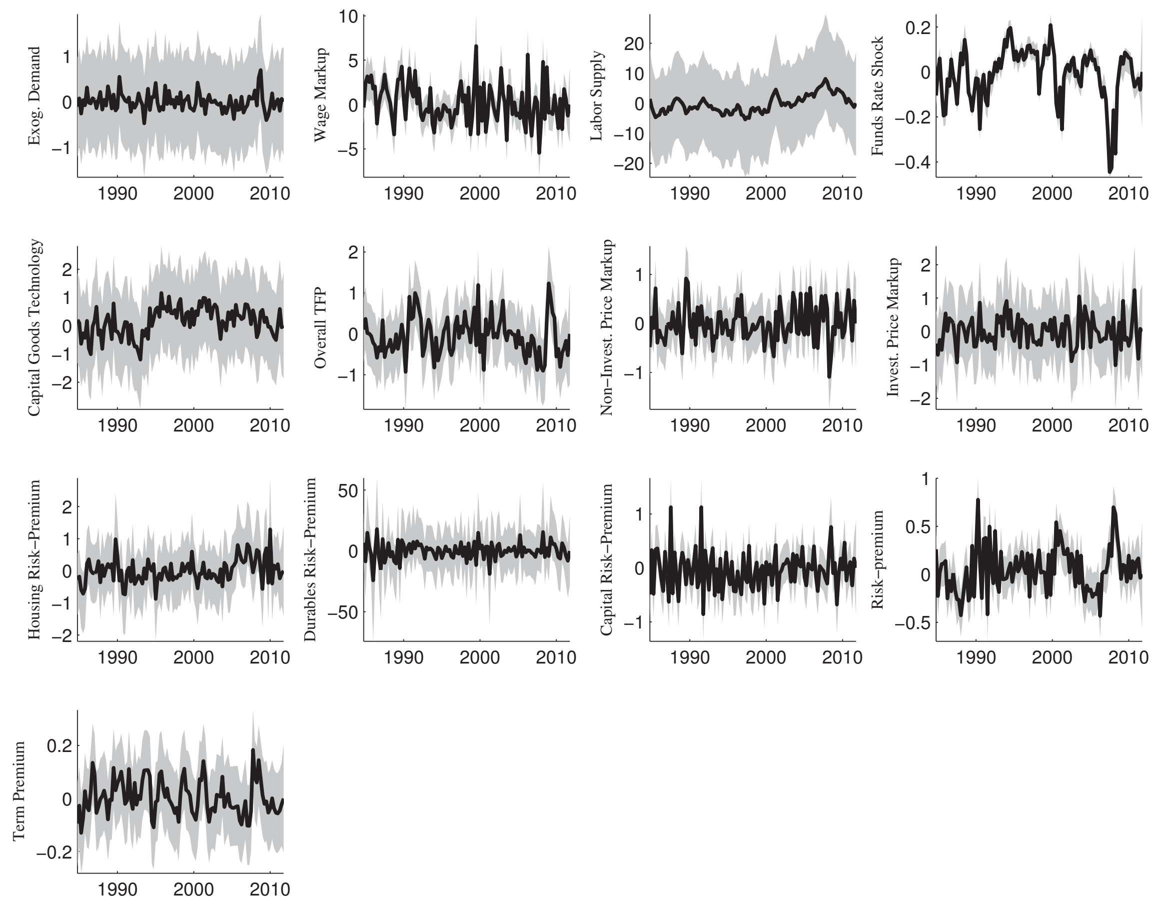


With regard to impulse responses, we highlight the responses to the most important shock, the aggregate risk premium, in figure 4. As we noted, this shock looks like a traditional demand shock, with an increase in the risk premium lowering real GDP, hours worked, and inflation; monetary policy offsets these negative effects somewhat by becoming more accommodative. As for responses to other disturbances, the impulse responses to a monetary policy innovation captures the conventional wisdom regarding the effects of such shocks. In particular, both household and business expenditures on durables (consumer durables, residential investment, and nonresidential investment) respond strongly (and with a hump-shape) to a contractionary policy shock, with more muted responses by nondurables and services consumption; each measure of inflation responds gradually, albeit more quickly than in some analyses based on vector autoregressions (VARs).[6]

Shocks to sectoral risk premia principally depress spending in the associated category of expenditure (e.g., an increase in the residential risk premium lowers residential investment), with offsetting positive effects on other spending (which is "crowded in").

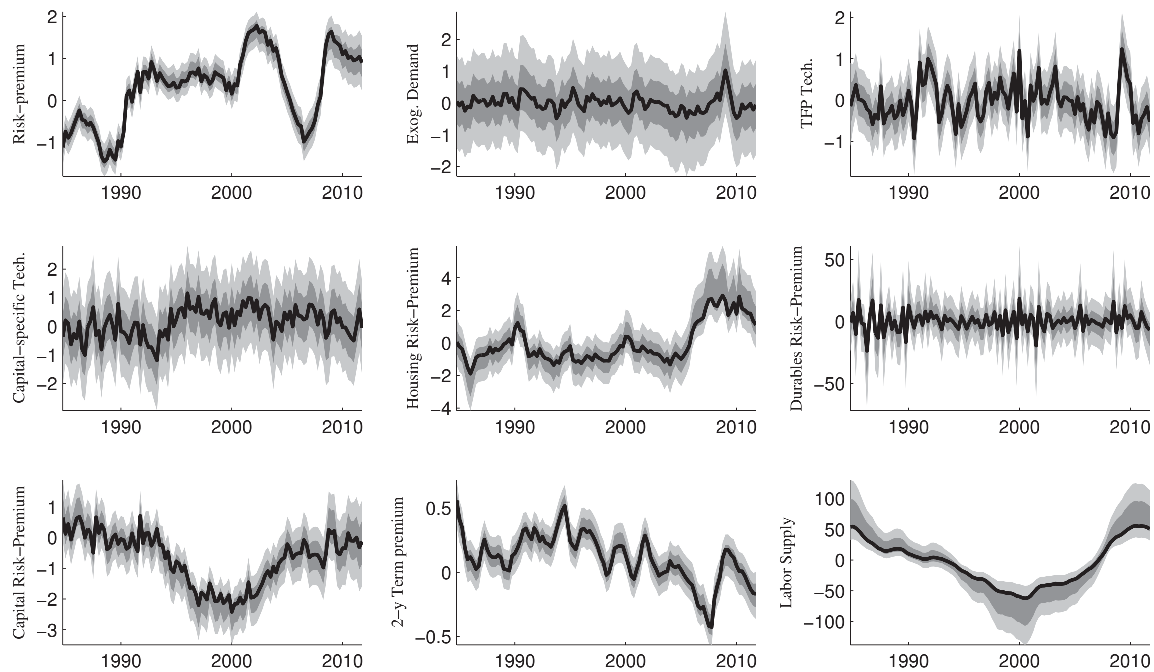
Following an economy-wide technology shock, output rises gradually to its long-run level; hours respond relatively little to the shock (in comparison to, for example, output), reflecting both the influence of stick prices and wages and the offsetting income and substitution effects of such a shock on households willingness to supply labor.

Figure 5: Innovations to Exogenous Processes



[6]This difference between VAR-based and DSGE-model based impulse responses has been highlighted elsewhere – for example, in the survey of Boivin, Kiley, and Mishkin (2010).

Figure 6: Exogenous Drivers



3.3 Estimates of Latent Variable Paths

Figures 5 and 6 report modal estimates of the model's structural shocks and the persistent exogenous fundamentals (i.e., risk premia and autonomous demand). These series have recognizable patterns for those familiar with U.S. economic fluctuations. For example, the risk premia jump at the end of the sample, reflecting the financial crisis and the model's identification of risk premia, both economy-wide and for housing, as key drivers.

Of course, these stories from a glance at the exogenous drivers yield applications for alternative versions of the EDO model and future model enhancements. For example, the exogenous risk premia can easily be made to have an endogenous component following the approach of Bernanke, Gertler, and Gilchrist (1999) (and indeed we have considered models of that type). At this point we view incorporation of such mechanisms in our baseline approach as premature, pending ongoing research on financial frictions, banking, and intermediation in dynamic general equilibrium models. Nonetheless, the EDO model captured the key financial disturbances during the last several years in its current specification, and examining the endogenous factors that explain these developments will be a topic of further study.

References

[Bernanke, Gertler, and Gilchrist (1999)] Bernanke, B., M. Gertler, and S. Gilchrist. 1999. The financial accelerator in a quantitative business cycle framework, In: John B. Taylor and Michael Woodford, Editor(s), Handbook of Macroeconomics, Elsevier, 1999, Volume 1, Part 3, Pages 1341-1393.

[Beveridge and Nelson (1981)] Beveridge, S. and C.R. Nelson. 1981. A new approach to the decomposition of economic time series into permanent and transitory components with particular attention to measurement of the business cycle, Journal of Monetary Economics vol. 7, Pages 151-174.

[Boivin et al. (2010)] Boivin, J., M. Kiley, and F.S. Mishkin. 2010. How Has the Monetary Transmission Mechanism Evolved Over Time? In B. Friedman and M. Woodford, eds., The Handbook of Monetary Economics, Elsevier.

[Carlstom et al (2012)] Carlstrom, Charles T., Timothy S. Fuerst and Matthias Paustian. 2012. How inflationary is an extended period of low interest rates?, Federal Reserve Bank of Cleveland Working Paper 1202.

[Chung et al. (2011)] Chung, Hess, J.P. Laforte, David L. Reifschneider, and John C. Williams. 2010. Have We Underestimated the Likelihood and Severity of Zero Lower Bound Events. Federal Reserve Bank of San Francisco Working Paper 2011-01 http://www.frbsf.org/publications/economics/papers/2011/wp11-01bk.pdf

[Edge, Kiley, and Laforte (2008)] Edge, R., Kiley, M., Laforte, J.P., 2008. Natural rate measures in an estimated DSGE model of the U.S. economy. Journal of Economic Dynamics and Control vol. 32(8), Pages 2512-2535.

[Edge, Kiley, and Laforte (2010)] Edge, R., Kiley, M., Laforte, J.P., 2010. A comparison of forecast performance between Federal Reserve staff forecasts, simple reduced-form models, and a DSGE model. Journal of Applied Econometrics vol. 25(4), Pages 720-754.

[Fisher (2006)] Fisher, Jonas D. M., 2006. The Dynamic Effects of Neutral and Investment-Specific Technology Shocks. Journal of Political Economy, University of Chicago Press, vol. 114(3), Pages 413-451.

[Gali (2011)] Gali, Jordi, 2011. The Return Of The Wage Phillips Curve. Journal of the European Economic Association vol. 9(3), pages 436-461.

[Hall (2010)] Hall, Robert E., 2010. Why Does the Economy Fall to Pieces after a Financial Crisis? Journal of Economic Perspectives vol. 24(4), Pages 3-20. http://www.aeaweb.org/articles.php?doi=10.1257/jep.24.4.3

[Kiley (2007)] Kiley, M., 2007. A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting. Journal of Money, Credit, and Banking 39, Pages 101-125.

[Kiley (2010a)] Kiley, M., 2010a. Habit Persistence, Non-separability between Consumption and Leisure, or Rule-of-Thumb Consumers: Which Accounts for the Predictability of Consumption Growth? The Review of Economics and Statistics vol. 92(3), Pages 679-683.

[Kiley (2010b)] Kiley, M., 2010b. Output Gaps. Federal Reserve Board Finance and Economics Discussion Series (FEDS), 2010-27.

[Kydland and Prescott (1982)] Kydland, Finn and Prescott, Edward. 1982. Time-to-build and Aggregate Fluctuations. Econometrica vol. 50(6), Pages 1345 - 1370.

[Laforte (2007)] Laforte, J., 2007. Pricing Models: A Bayesian DSGE Approach to the U.S. Economy. Journal of Money, Credit, and Banking vol. 39, Pages 127-54.

[Smets and Wouters (2007)] Smets, F., Wouters, R., 2007. Shocks and Frictions in the US Busines Cycles: A Bayesian DSGE Approach. American Economic Review, American Economic Association, vol. 97(3), Pages 586-606.

[Wieland and Wouters (2010)] Wieland, Volker and Wolters, Maik H, 2010. The Diversity of Forecasts from Macroeconomic Models of the U.S. Economy. CEPR Discussion Papers 7870, C.E.P.R. Discussion Papers.

FRBNY DSGE Model: Research Directors Draft
August 28, 2014

Summary of the Forecasts

The FRBNY model forecasts are obtained using data released through 2014Q2, augmented for 2014Q3 with the FRBNY staff forecasts for real GDP growth, core PCE inflation, and growth in total hours, and with values of the federal funds rate and the spread between Baa corporate bonds and 10-year Treasury yields based on 2014Q3 observations. The expected federal funds rate is constrained to equal market expectations, as measured by OIS rates, through 2015Q2. This constraint is implemented via anticipated policy shocks, whose standard deviations are estimated using FFR expectations since 2008Q4, when the zero bound became binding. The 2014Q3 staff projections and OIS rates are those that were available on August 28, 2014.

The FRBNY DSGE forecast for 2014 did not change substantially compared to June: for the short-term the forecast features slightly lower real GDP and higher inflation, where the change in the inflation forecast mainly reflects slightly higher than expected inflation in Q2. However, the forecast is roughly unchanged for the rest of the forecasting horizon. Specifically, relative to June, the GDP growth forecast for 2014 and 2015 (Q4/Q4) decreased to 1.9 and 2.0, respectively, from 2.2 percent, while the forecasts for 2016 and 2017 (Q4/Q4) are at 1.7 percent and 1.8 percent respectively, slightly lower than in June. For inflation, the mean core PCE inflation for 2014 is projected to be 1.6 percent, higher than the 1.4 percent projected in June. Inflation gradually returns closer to the long term objective of 2 percent over the forecast horizon. The point forecasts are 1.4, 1.7, and 1.9 for 2015 through 2017, roughly unchanged relative to the June point forecasts. Uncertainty around real GDP growth and inflation forecasts has diminished for 2014 because the model uses the 2014Q3 nowcast as data, but is broadly unchanged otherwise. For GDP growth, the 68 percent bands cover the intervals 1.2 to 2.4 percent in 2014, -1.1 to 4.5 percent in 2015, -1.5 to 4.9 in 2016, and -1.3 to 5.1 in 2017. For inflation, the 68 percent probability bands range from 0.7 to 2.7 percent throughout 2017.

The dynamics behind medium-to-long-term FRBNY DSGE forecasts can be described as follows. The headwinds from the financial crisis are dissipating over time, and their negative effects have started to wane. In fact, spread shocks, which were the main driver if the Great

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Recession, provide a positive contribution starting in early 2014. This is consistent with the significant reduction in perceived risks and the ensuing compression in credit spreads observed recently. However, in the past few years the economy has been buffeted by mostly negative shocks, which have slowed down the return to trend. At the same time the fact that output is still below trend implies that inflation is below the long term objective. These negative shocks have been partly compensated by expansionary monetary policy. However, the positive effect of this policy accommodation on the level of output begins to wane from the end of 2014 onward, implying a negative effect on growth.

The FRBNY model projects the FFR to be roughly 2 percent by the end of 2016, about 2 percentage points below its steady state value. The slow return of the FFR to steady state is mostly driven by the endogenous response of policy to the relatively weak economy, rather than by accommodative policy shocks.

The Model and Its Transmission Mechanism

General Features of the Model

The FRBNY DSGE model is a medium-scale, one-sector, dynamic stochastic general equilibrium model. It builds on the neoclassical growth model by adding nominal wage and price rigidities, variable capital utilization, costs of adjusting investment, and habit formation in consumption. The model follows the work of Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007), but also includes credit frictions, as in the financial accelerator model developed by Bernanke, Gertler, and Gilchrist (1999). The actual implementation of the credit frictions closely follows Christiano, Motto, and Rostagno (2009).

In this section, we briefly describe the microfoundations of the model, including the optimization problem of the economic agents and the nature of the exogenous processes. The innovations to these processes, which we refer to as "shocks," are the drivers of macroeconomic fluctuations. The model identifies these shocks by matching the model dynamics with six quarterly data series: real GDP growth, core PCE inflation, the labor share, aggregate hours worked, the effective federal funds rate (FFR), and the spread between Baa corporate bonds and 10-year Treasury yields. Model parameters are estimated from 1984Q1 to the present using Bayesian methods. Details on the structure of the model, data sources, and results of the estimation procedure can be found in Del Negro et al. (2013).

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The economic units in the model are households, firms, banks, entrepreneurs, and the government. (Figure 1 describes the interactions among the various agents, the frictions and the shocks that affect the dynamics of this economy.)

Households supply labor services to firms. The utility they derive from leisure is subject to a random disturbance, which we call "labor supply" shocks (this shock is sometimes also referred to as a "leisure" shock). Labor supply shocks capture exogenous movements in labor supply due to such factors as demographics and labor market imperfections. The labor market is also subject to frictions because of nominal wage rigidities. These frictions play an important role in the extent to which various shocks affect hours worked. Households also have to choose the amount to consume and save. Their savings take the form of deposits to banks and purchases of government bills. Household preferences take into account habit persistence, a characteristic that affects their consumption smoothing decisions.

Monopolistically competitive firms produce intermediate goods, which a competitive firm aggregates into the single final good that is used for both consumption and investment. The production function of intermediate producers is subject to "total factor productivity" (TFP) shocks. Intermediate goods markets are subject to price rigidities. Together with wage rigidities, this friction is quite important in allowing demand shocks to be a source of business cycle fluctuations, as countercyclical mark-ups induce firms to produce less when demand is low. Inflation evolves in the model according to a standard, forward-looking New Keynesian Phillips curve, which determines inflation as a function of marginal costs, expected future inflation, and "mark-up" shocks. Mark-up shocks capture exogenous changes in the degree of competitiveness in the intermediate goods market. In practice, these shocks capture unmodeled inflation pressures, such as those arising from fluctuations in commodity prices.

Financial intermediation involves two actors, *banks* and *entrepreneurs*, whose interaction captures imperfections in financial markets. These actors should not be interpreted in a literal sense, but rather as a device for modeling credit frictions. Banks take deposits from households and lend them to entrepreneurs. Entrepreneurs use their own wealth and the loans from banks to acquire capital. They then choose the utilization level of capital and rent the capital to intermediate good producers. Entrepreneurs are subject to idiosyncratic disturbances in their ability to manage the capital. Consequently, entrepreneurs' revenue may not be enough to repay their loans, in which case they default. Banks protect against default risk by pooling loans to all entrepreneurs and charging a spread over the deposit

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rate. Such spreads vary endogenously as a function of the entrepreneurs' leverage, but also exogenously depending on the entrepreneurs' riskiness. Specifically, mean-preserving changes in the volatility of entrepreneurs' idiosyncratic shocks lead to variations in the spread (to compensate banks for changes in expected losses from individual defaults). We refer to these exogenous movements as "spread" shocks. Spread shocks capture financial intermediation disturbances that affect entrepreneurs' borrowing costs. Faced with higher borrowing costs, entrepreneurs reduce their demand for capital, and investment drops. With lower aggregate demand, there is a contraction in hours worked and real wages. Wage rigidities imply that hours worked fall even more (because nominal wages do not fall enough). Price rigidities mitigate price contraction, further depressing aggregate demand.

Capital producers transform general output into capital goods, which they sell to the entrepreneurs. Their production function is subject to investment adjustment costs: producing capital goods is more costly in periods of rapid investment growth. It is also subject to exogenous changes in the "marginal efficiency of investment" (MEI). These MEI shocks capture exogenous movements in the productivity of new investments in generating new capital. A positive MEI shock implies that fewer resources are needed to build new capital, leading to higher real activity and inflation, with an effect that persists over time. Such MEI shocks reflect both changes in the relative price of investment versus that of consumption goods (although the literature has shown the effect of these relative price changes to be small), and most importantly financial market imperfections that are not reflected in movements of the spread.

Finally, the *government* sector comprises a monetary authority that sets short-term interest rates according to a Taylor-type rule and a fiscal authority that sets public spending and collects lump-sum taxes to balance the budget. Exogenous changes in government spending are called "government" shocks (more generally, these shocks capture exogenous movements in aggregate demand). All exogenous processes are assumed to follow independent AR(1) processes with different degrees of persistence, except for i.i.d. "policy" shocks, which are exogenous disturbances to the monetary policy rule.

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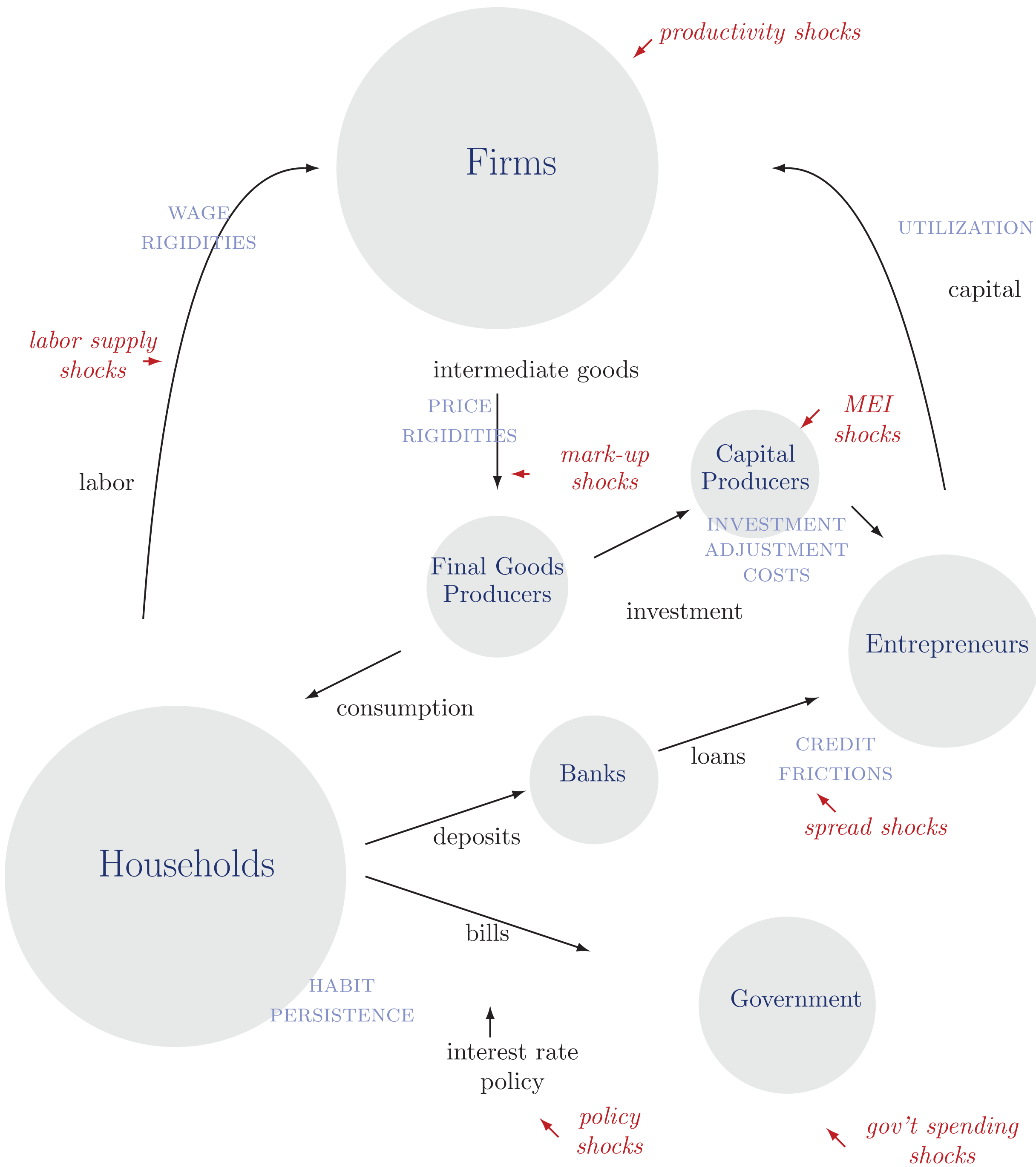
Figure 1: Model Structure



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The Model's Transmission Mechanism

In this section, we illustrate some of the key economic mechanisms at work in the model's equilibrium. We do so with the aid of the impulse response functions to the main shocks hitting the economy, which we report in figures 8 to 14.

We start with the shock most closely associated with the Great Recession and the severe financial crisis that characterized it: the spread shock. As discussed above, this shock stems from an increase in the perceived riskiness of borrowers, which induces banks to charge higher interest rates for loans, thereby widening credit spreads. As a result of this increase in the expected cost of capital, entrepreneurs' borrowing falls, hindering their ability to channel resources to the productive sector via capital accumulation. The model identifies this shock by matching the behavior of the ratio of the Baa corporate bond rate to the 10-year Treasury rate, and the spread's comovement with output growth, inflation, and the other observables. Figure 8 shows the impulse responses of the variables used in the estimation to a one-standard-deviation innovation in the spread shock. An innovation of this size increases the observed spread by roughly 35 basis points (bottom right panel). This leads to a reduction in investment and consequently to a reduction in output growth (top left panel) and hours worked (top right panel). The fall in the level of hours is fairly sharp in the first year and persists for many quarters afterwards, leaving the labor input not much higher than at the trough five years after the impulse. Of course, the effects of this same shock on GDP growth, which roughly mirrors the change in the level of hours, are much more short-lived. Output growth returns to its steady state level about two years after the shock hits, but it barely moves above it after that, implying no catch up of the level of GDP towards its previous trend (bottom left panel). The persistent drop in the level of economic activity due to the spread shock also leads to a prolonged decline in real marginal costs - which in this model map one-to-one into the labor share (middle left panel)- and, via the New Keynesian Phillips curve, in inflation (middle right panel). Finally, policymakers endogenously respond to the change in the inflation and real activity outlook by cutting the federal funds rate (left panel on the third row).

Very similar considerations hold for the MEI shock, which represents a direct hit to the 'technological' ability of entrepreneurs to transform investment goods into productive capital, rather than an increase in their funding cost. Although the origins of these two shocks are different, the fact that they both affect the creation of new capital implies very similar effects on the observable variables, as shown by the impulse responses in figure 9. In particular, a

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positive MEI shock also implies a very persistent increase in investment, output and hours worked, as well as in the labor share and hence inflation. The key difference between the two impulses, which is also what allows us to tell them apart empirically, is that the MEI shock leaves spreads virtually unchanged (bottom right panel).

Another shock that plays an important role in the model, and whose estimated contribution to the Great Recession and its aftermath increased in light of the latest data revisions, is the TFP shock. As shown in figure 10, a positive TFP shock has a large and persistent effect on output growth, even if the response of hours is muted in the first few quarters (and slightly negative on impact). This muted response of hours is due to the presence of nominal rigidities, which prevent an expansion of aggregate demand sufficient to absorb the increased ability of the economy to supply output. With higher productivity, marginal costs and thus the labor share fall, leading to lower inflation. The policy rule specification implies that this negative correlation between inflation and real activity, which is typical of supply shocks, produces offsetting forces on the interest rate, which as a result moves little. These dynamics make the TFP shock particularly suitable to account for the first phase of the recovery, in which GDP growth was above trend, but hours and inflation remained weak. With the recent softening of the expansion, though, the role of TFP shocks is fading.

The last shock that plays a relevant role in the current economic environment is the mark-up shock, whose impulse response is depicted in figure 11. This shock is an exogenous source of inflationary pressures, stemming from changes in the market power of intermediate goods producers. As such, it leads to higher inflation and lower real activity, as producers reduce supply to increase their desired markup. Compared to those of the other prominent supply shock in the model, the TFP shock, the effects of markup-shocks feature significantly less persistence. GDP growth falls on impact after mark-ups increase, but returns above average after about one year, and the effect on the level of output is absorbed in a little over four years. Inflation is sharply higher, but only for a couple of quarters, leading to a temporary spike in the nominal interest rate, as monetary policy tries to limit the pass-through of the shock to inflation. Unlike in the case of TFP shocks, however, hours fall immediately, mirroring the behavior of output.

Forecasts

	Unconditional Forecast							
	2014 (Q4/Q4)		2015 (Q4/Q4)		2016 (Q4/Q4)		2017 (Q4/Q4)	
	August	June	August	June	August	June	August	June
Core PCE	1.5	1.0	1.4	1.2	1.7	1.6	1.9	1.8
Inflation	(1.3,1.6)	(0.6,1.3)	(0.7,2.0)	(0.4,1.8)	(0.9,2.4)	(0.7,2.3)	(1.1,2.7)	(1.0,2.6)
Real GDP	1.9	0.2	1.9	1.4	1.6	1.7	1.8	2.0
Growth	(1.2,2.4)	(-1.1,1.2)	(-1.2,4.3)	(-1.8,3.9)	(-1.6,4.7)	(-1.5,4.7)	(-1.4,5.1)	(-1.1,5.2)

	Conditional Forecast*							
	2014 (Q4/Q4)		2015 (Q4/Q4)		2016 (Q4/Q4)		2017 (Q4/Q4)	
	August	June	August	June	August	June	August	June
Core PCE	1.6	1.4	1.4	1.3	1.7	1.7	1.9	1.9
Inflation	(1.4,1.7)	(1.0,1.7)	(0.7,2.0)	(0.6,2.0)	(0.9,2.4)	(0.8,2.4)	(1.1,2.7)	(1.0,2.7)
Real GDP	1.9	2.2	2.0	2.2	1.7	1.8	1.8	2.0
Growth	(1.2,2.4)	(0.9,3.2)	(-1.1,4.5)	(-1.0,4.7)	(-1.5,4.9)	(-1.3,4.9)	(-1.3,5.1)	(-1.2,5.2)

*The unconditional forecasts use data up to 2014Q2, the quarter for which we have the most recent GDP release, as well as the federal funds rate and spreads data for 2014Q3. In the conditional forecasts, we further include the 2014Q3 FRBNY projections for GDP growth, core PCE inflation, and growth in total hours worked as additional data points. Numbers in parentheses indicate 68 percent probability intervals.

We detail the forecast of three main variables over the horizon 2014-2017: real GDP growth, core PCE inflation and the federal funds rate. To obtain the forecast we set federal funds rate expectations equal to market expectations for the federal funds rate (as measured by OIS rates) through 2015Q2. We capture policy anticipation by adding anticipated monetary policy shocks to the central bank's reaction function starting in 2008Q4, the beginning of the zero bound period, following the methodology of Laseen and Svensson (2009). We estimate the standard deviation of the anticipated shocks as in Campbell et al. (2012), but use only post-2008Q4 data.

The table above presents Q4/Q4 forecasts for real GDP growth and inflation for 2014-2017, with 68 percent probability intervals. We include two sets of forecasts. The *unconditional* forecasts use data up to 2014Q2, the quarter for which we have the most recent GDP release, as well as the federal funds rate and spreads data for 2014Q3 (we use the average realizations for the quarter up to the forecast date). In the *conditional* forecasts, we further include the 2014Q3 FRBNY staff projections for GDP growth, core PCE inflation, and hours worked as additional data points (as of August 28, projections for 2014Q3 are 3 percent for output growth, 1.7 percent for core PCE inflation, and 2.1 percent growth for hours worked). Treating the 2014Q3 staff forecasts as data allows us to incorporate information about the current quarter into the DSGE forecasts for the subsequent quarters. In

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addition to providing the current forecasts, the table reports the forecasts included in the DSGE memo forwarded to the FOMC in advance of its June 2014 meeting.

Figure 2 presents quarterly forecasts, both unconditional (left panels) and conditional (right panels). In the graphs, the black line represents data, the red line indicates the mean forecast, and the shaded areas mark the uncertainty associated with our forecast as 50, 60, 70, 80 and 90 percent probability intervals. Output growth and inflation are expressed in terms of percent annualized rates, quarter to quarter. The interest rate is the annualized quarterly average of the daily series. The bands reflect both parameter and shock uncertainty. Figure 3 compares the current forecasts with the September forecasts. Our discussion will mainly focus on the conditional forecasts, which are those reported in the memo to the FOMC.

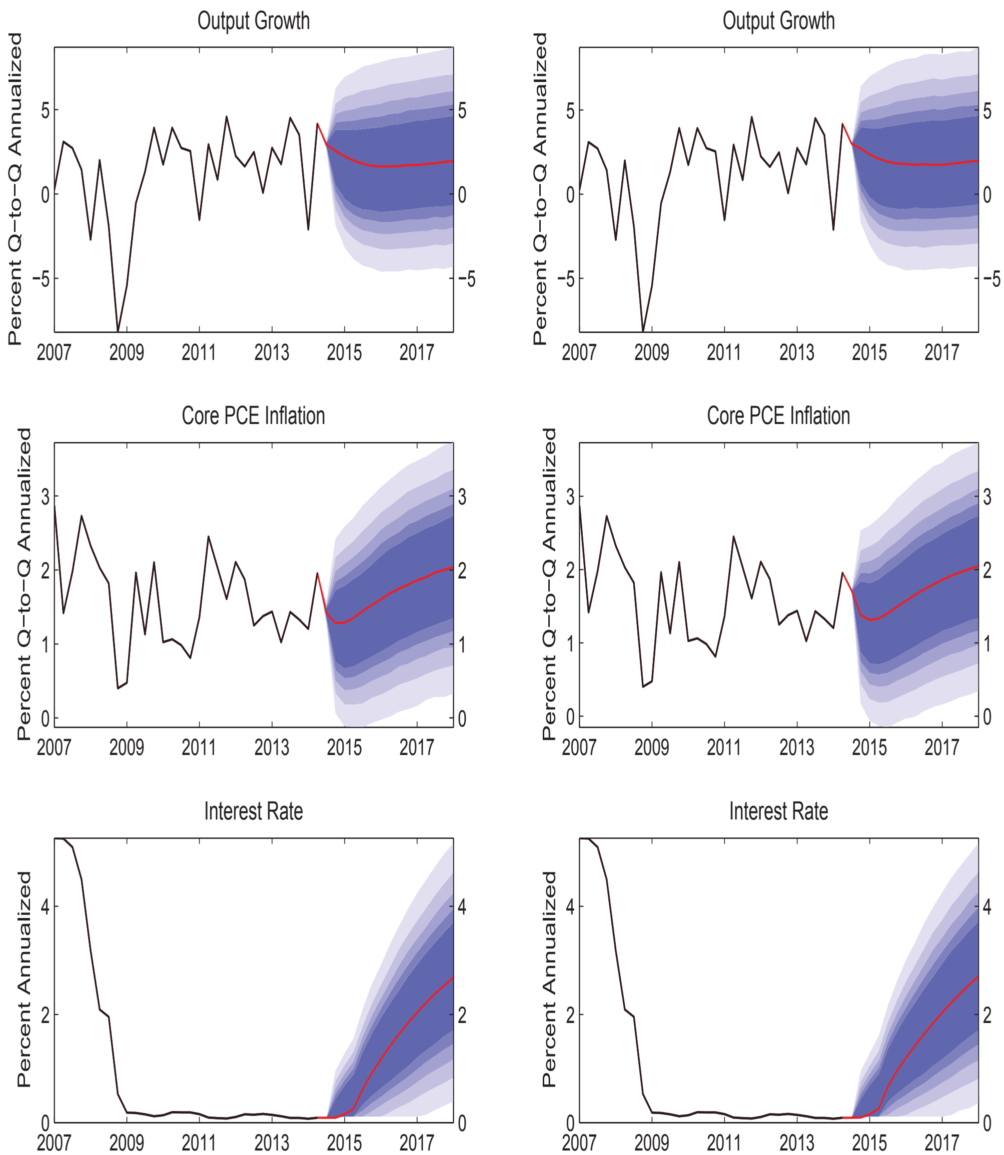
The FRBNY DSGE forecast for 2014 did not change substantially compared to June: for the short-term the forecast features slightly lower real GDP and higher inflation, mainly reflecting higher than expected inflation in Q2. However, the forecast is roughly unchanged for the rest of the forecasting horizon. Of note, in August conditional and unconditional forecasts are very similar. This reflects the fact that the unconditional forecast now incorporates the real GDP increase in 2014Q2, which was the source of the gap between the two forecasts in June.

Relative to June, the GDP growth forecast for 2014 and 2015 (Q4/Q4) decreased to 1.9 and 2.0 from 2.2 percent, respectively, while the forecasts for 2016 and 2017 (Q4/Q4) are slightly lower at 1.7 percent and 1.8 percent respectively. For inflation, the mean core PCE inflation for 2014 is projected to be 1.6 percent, higher than the 1.4 percent projected in June. Inflation gradually returns closer to the long term objective of 2 percent over the forecast horizon. The point forecasts are 1.4, 1.7, and 1.9 for 2015 through 2017, roughly unchanged relative the June point forecasts. Uncertainty around real GDP growth and inflation forecasts has diminished for 2014 (partly because we treat the 2014Q3 nowcast as data) but is broadly unchanged otherwise. For GDP growth, the 68 percent bands cover the intervals 1.2 to 2.4 percent in 2014, -1.1 to 4.5 percent in 2015, -1.5 to 4.9 in 2016, and -1.3 to 5.1 in 2017. For inflation, the 68 percent probability bands range from 0.7 to 2.7 percent throughout 2017.

Finally, as mentioned above, we constrain the federal funds rate expectations through 2015Q2 to be equal to the expected federal fund rate as measured by the OIS rates on August 28; after that the federal funds rate rises gradually and is forecasted to be between 1 3/4 and 2 percent at the end of 2016 and between 2 1/2 and 2 3/4 percent by the end of 2017.

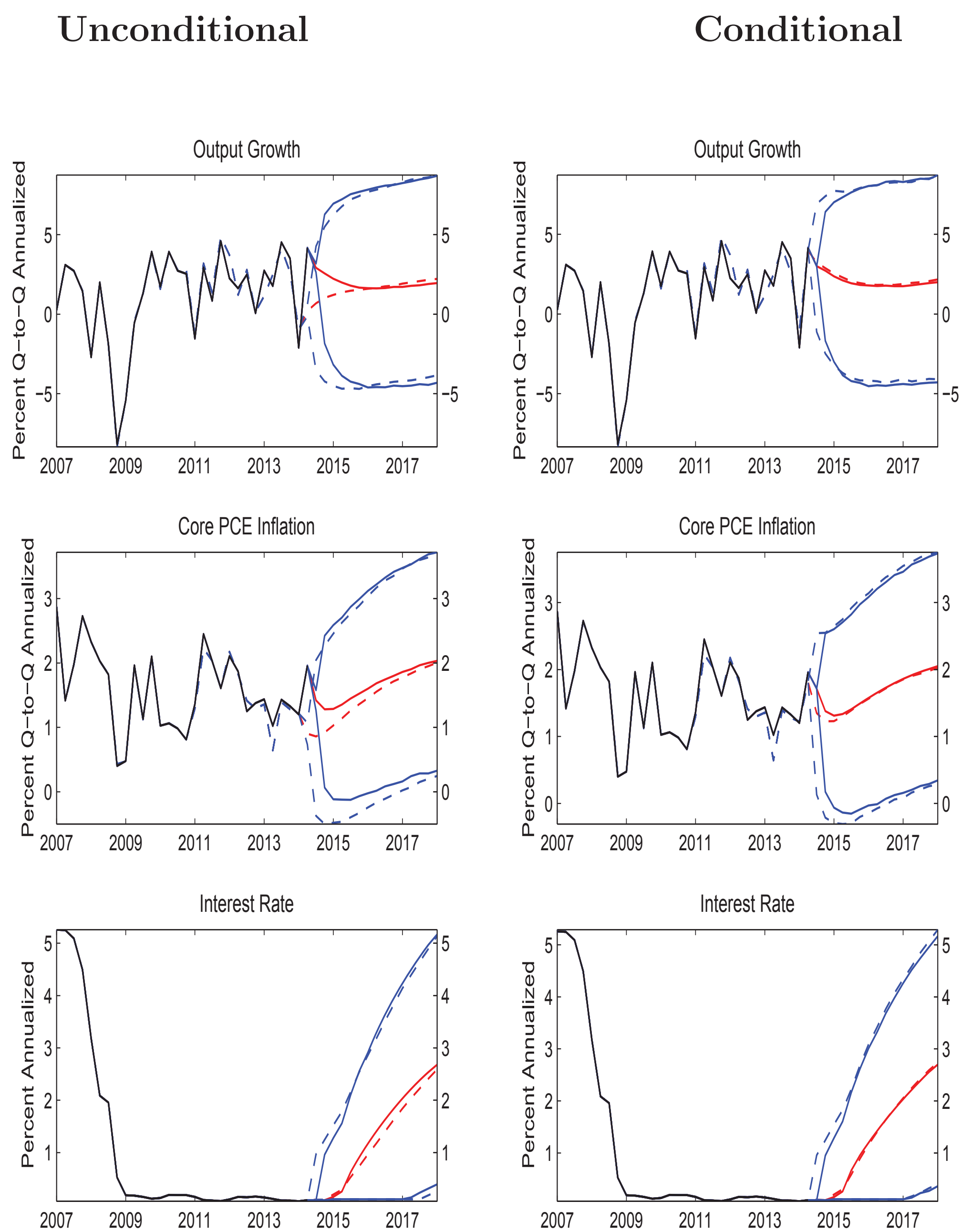
Figure 2: Forecasts

Unconditional **Conditional**



Black lines indicate data, red lines indicate mean forecasts, and shaded areas mark the uncertainty associated with our forecast as 50, 60, 70, 80, and 90 percent probability intervals.

Figure 3: Change in Forecasts



Solid (dashed) red and blue lines represent the mean and the 90 percent probability intervals of the current (previous) forecast.

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Interpreting the Forecasts

We use the shock decomposition shown in Figure 4 to interpret the forecasts. This figure quantifies the importance of each shock for output growth, core PCE inflation, and the federal funds rate (FFR) from 2007 on, by showing the extent to which each of the disturbances contributes to keeping the variables from reaching their long-run values. Specifically, in each of the three panels the solid line (black for realized data, red for mean forecast) shows the variable in deviation from its steady state (for output, the numbers are per capita, as the model takes population growth as exogenous; for both output and inflation, the numbers are quarter-to-quarter annualized). The bars represent the contribution of each shock to the deviation of the variable from steady state, that is, the counterfactual values of output growth, inflation, and the federal funds rate (in deviations from the mean) obtained by setting all other shocks to zero. By construction, for each observation the bars sum to the value of the solid line.

The dynamics behind the FRBNY DSGE forecast can be described as follows. The headwinds from the financial crisis are dissipating over time but at a very slow pace, implying only a small effect on growth shown by the bars capturing the effect of spread shocks. Recall that spread shocks were the main drivers of the Great Recession, and that their effect on output is very persistent, with a peak reached after almost three years (see Figure 8). As the forecast horizon unfolds, the negative effect of the credit shocks that generated the Great Recession start to wane. In fact, these shocks provide a positive contribution to growth starting in early 2014 (see purple bars), consistent with the significant reduction in perceived risks and the ensuing compression in credit spreads observed recently.

However, in the past few years the economy has been buffeted by several negative shocks, mostly marginal efficiency of investment (MEI) shocks, which have further slowed down the return of the economy to trend. The cumulative impact of these shocks on the level of output has not yet reached its full brunt, and consequently they still exert a negative impact on growth (see azure bars). Since MEI shocks are the main reason why the economy is below trend, they also explain – via the New Keynesian Phillips curve – the fact that inflation is below both steady state and the FOMC long run target.

Many of these negative shocks have been compensated by expansionary monetary policy. In particular, forward-guidance about the future path of the federal funds rate (captured here by anticipated policy shocks) has played an important role in counteracting these headwinds, and has lifted output and inflation in past years. However, the positive effect of this policy

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accommodation on the level of output begins to wane at the end of 2014 and onward, implying a negative effect on growth.

The shock decomposition for inflation also shows that much of its high frequency movements are explained by mark-up shocks (green bars), which capture the effect of cost-push phenomena like commodity price shocks. Positive markup shocks lead to increased inflation and lower output growth, as shown by the shock decomposition for output, but have only a temporary impact on both and hence little impact on the forecast. Finally, the model partly explains the recent improvements in the labor market via favorable labor supply shocks. Broadly speaking, these shocks capture frictions in labor markets, implying that these frictions have recently become less of an obstacle to the recovery.

Finally, the fact that both economic activity and inflation are below trend push interest down because of the policy reaction function. In fact, the shock decomposition shows that the slow return of the federal funds rate to steady state is mostly driven by the endogenous response of policy to the weak economy, rather than by policy shocks. The orange bars in Figure 4, show that the cumulative impact of policy accommodation currently amounts to about 70 basis points. The impact of forward guidance implies that the renormalization path is slower than that implied by the estimated rule, with the FFR reaching roughly 2 percent by the end of 2016.

Forecasts without Incorporating Federal Funds Rate Expectations

As mentioned above, we add federal funds rate expectations from 2008Q4 through 2015Q2 to the usual set of observables, to incorporate market expectations and forward guidance into our outlook (see Del Negro et al. (2013) for details). The inclusion of this information is made possible by including anticipated shocks in the central bank's reaction function, following Laseen and Svensson (2009). The model can therefore match the information about federal funds rate expectations in two different ways: (i) via the anticipated policy shocks, which capture pre-announced deviations from the estimated policy rule (as in "we expect interest rates to be low because monetary policy is unusually accommodative"); and (ii) by changing its assessment of the state of the economy (as in "we expect interest rates to be low because the state of the economy is worse than previously estimated"). The two channels capture the exogenous and endogenous component of monetary policy, respectively. We discussed the first channel – the effect of anticipated shocks – in the previous section.

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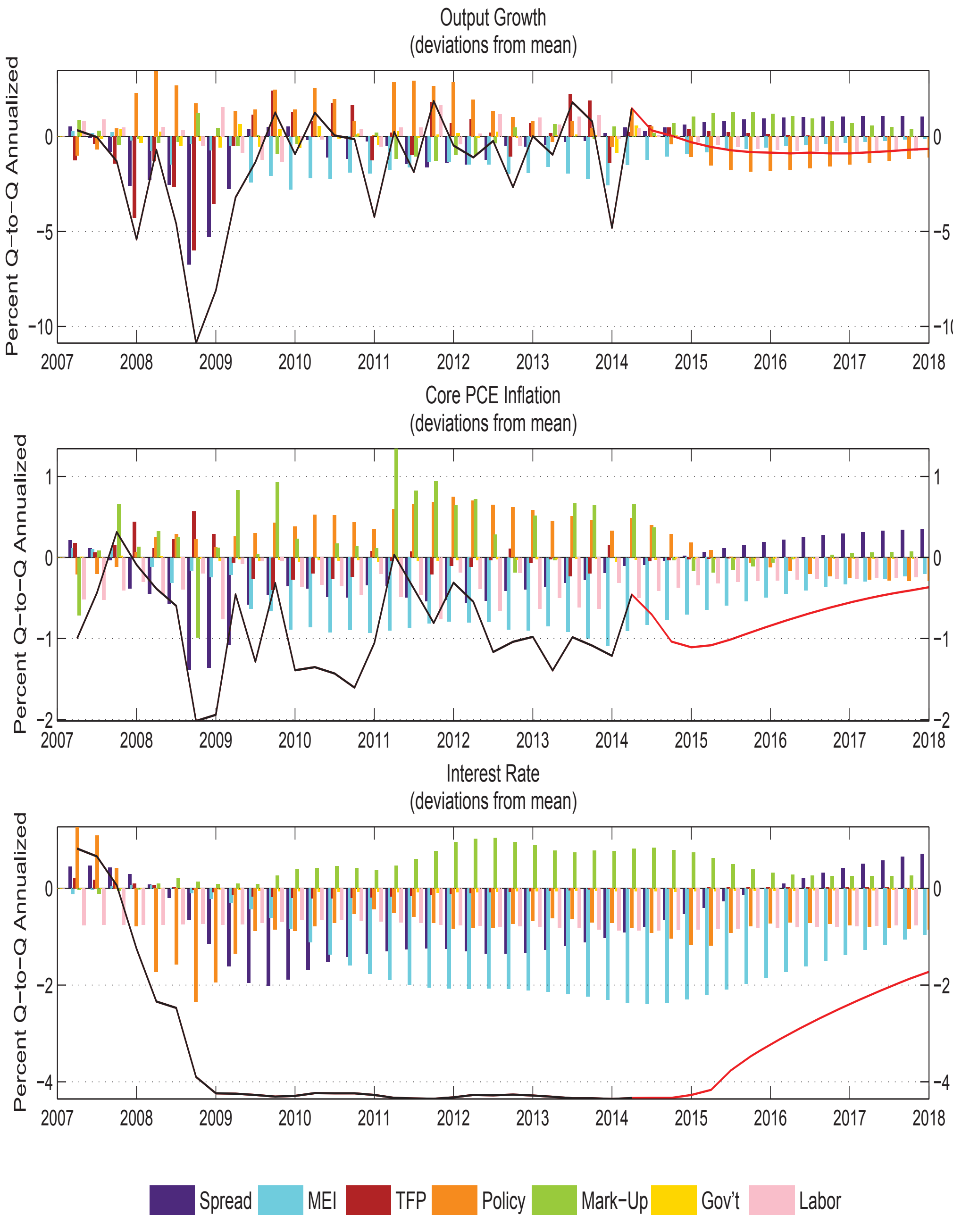
Figure 7 shows unconditional (left panels) and conditional (right panels) forecasts without incorporating federal funds rate expectations (dashed lines) as well as our baseline forecasts (solid lines). The figure shows that the model interprets the data on expected future federal funds rates as signaling a relatively weak state of the economy. Therefore forecasts are a bit more optimistic when disregarding the information provided by expected future federal funds rates. In particular, output growth and inflation forecasts are slightly higher, despite a tighter monetary policy. Lift-off occurs sooner in the model when expected future federal funds rates are not constrained, with the federal funds rate reaching almost 1.0 percent at the end of 2014 and about 3 percent by the end of 2016.

Figure 4: Shock Decomposition



The shock decomposition is presented for the conditional forecast. The solid lines (black for realized data, red for mean forecast) show each variable in deviation from its steady state. The bars represent the shock contributions; specifically, the bars for each shock represent the counterfactual values for the observables (in deviations from the mean) obtained by setting all other shocks to zero.

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Figure 5: Shock Histories

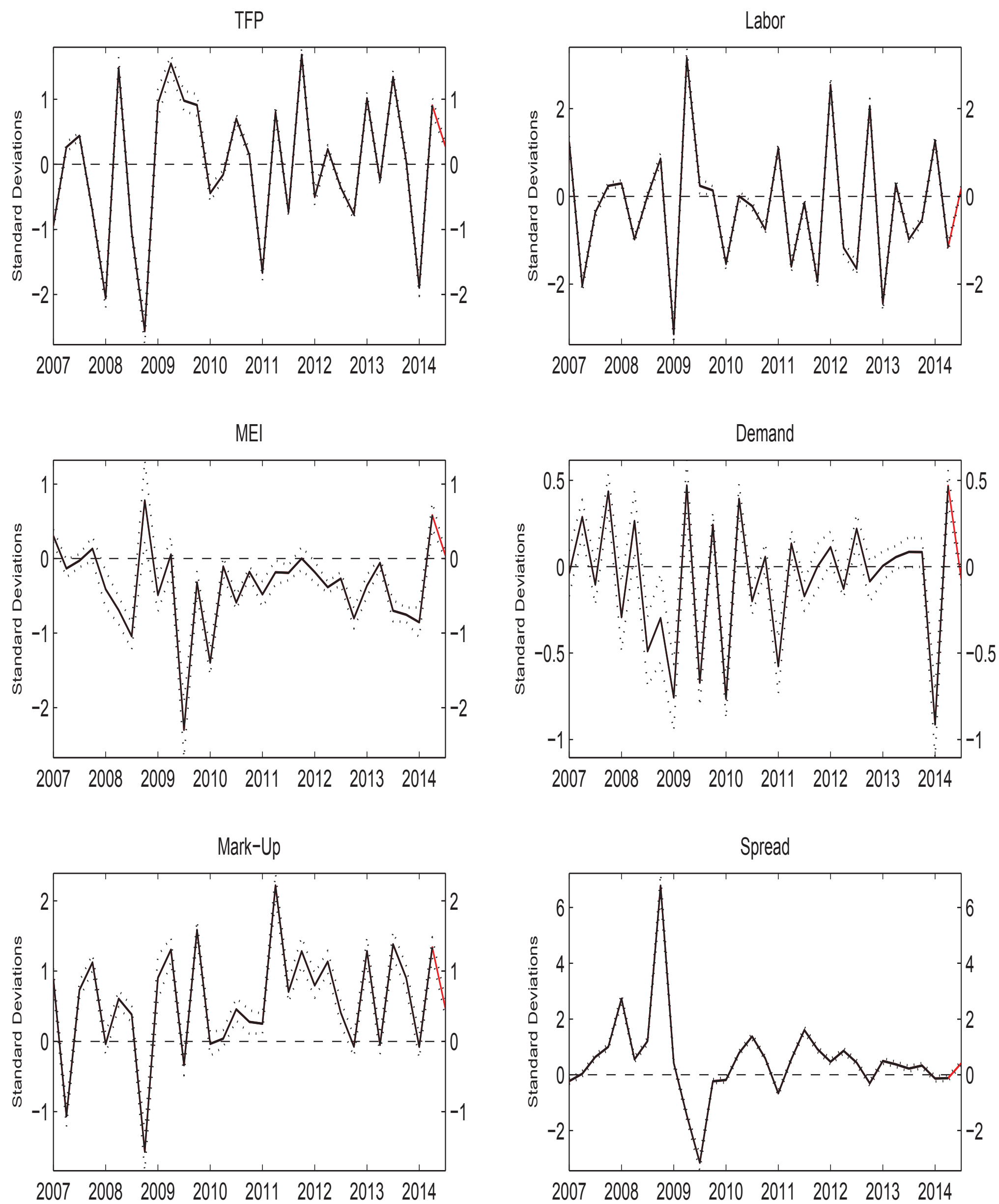

Figure 6: Anticipated Shock Histories

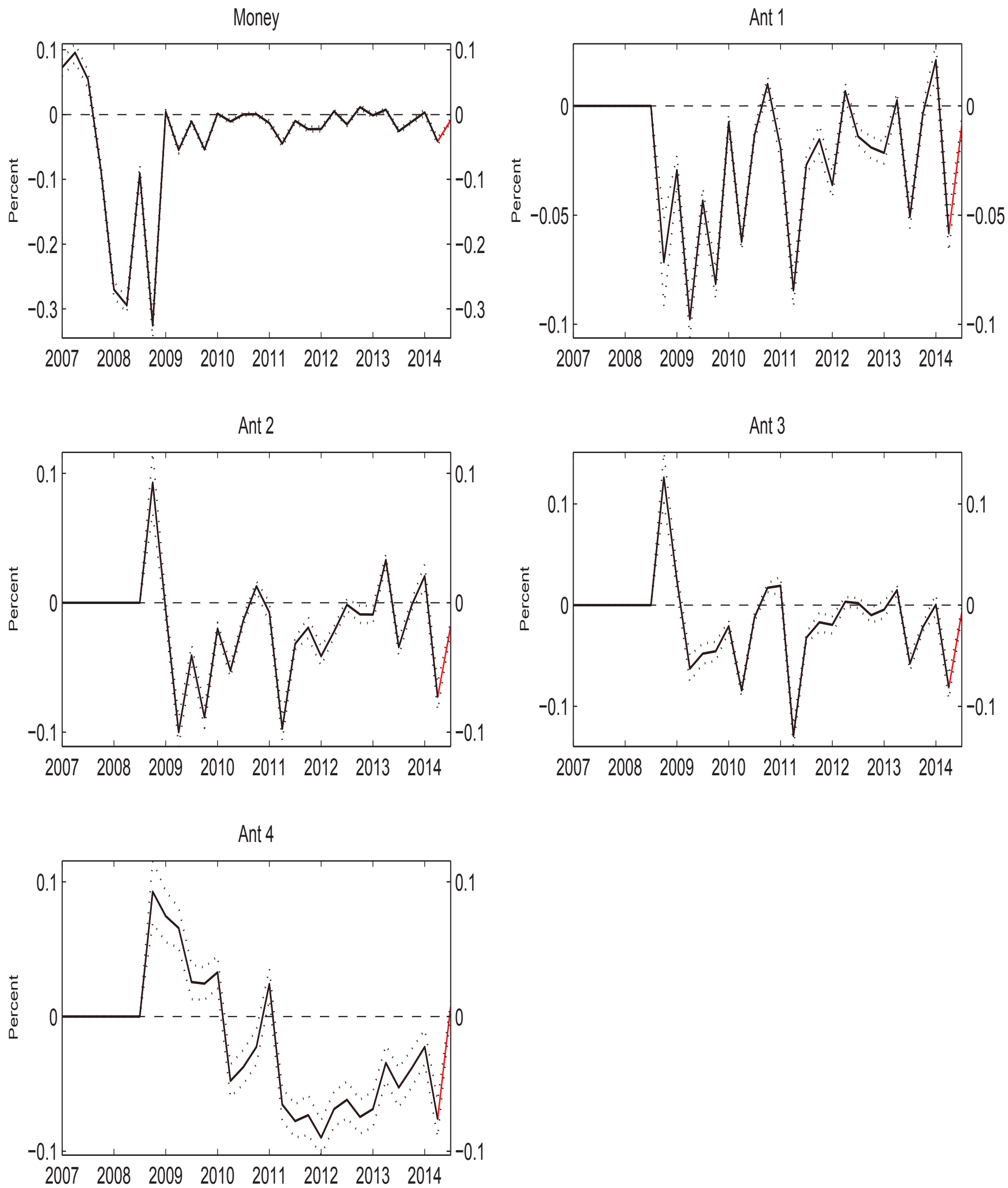

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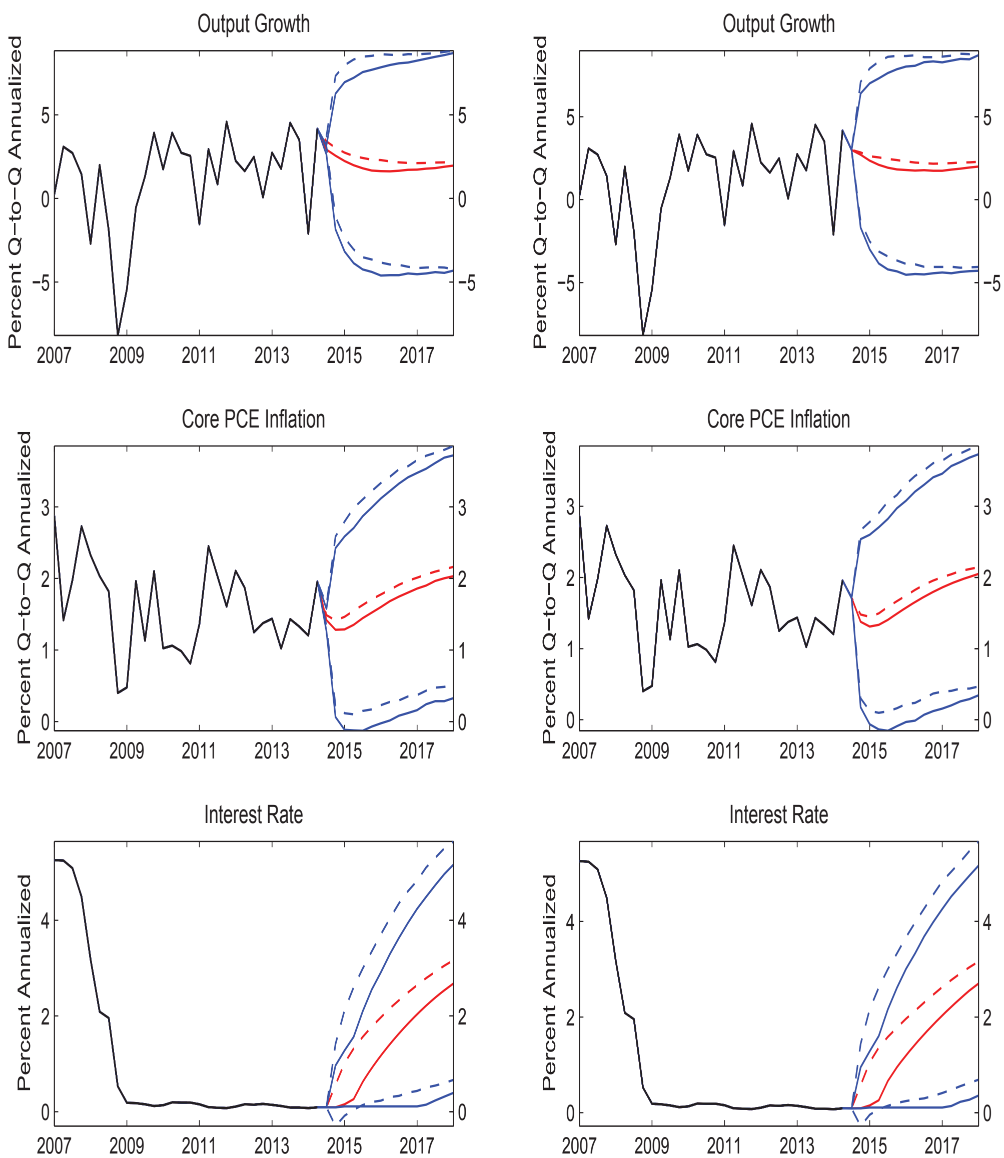
Figure 7: Effect of Incorporating FFR Expectations

Unconditional **Conditional**



Solid (dashed) red lines represent the mean for the forecast with (without) incorporating FFR expectations. Solid and dashed blue lines represent the relative 90 percent probability intervals.

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Figure 8: Responses to a Spread Shock

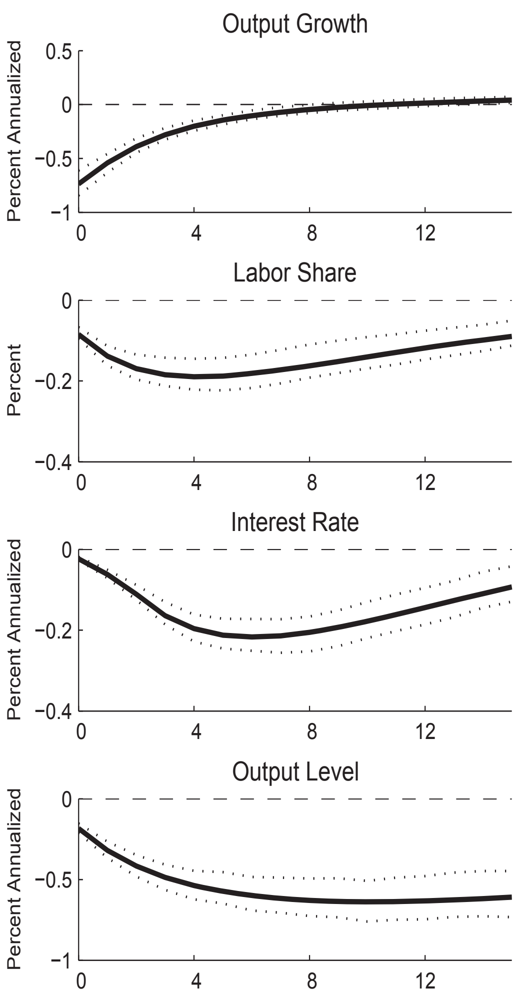

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Figure 9: Responses to an MEI Shock

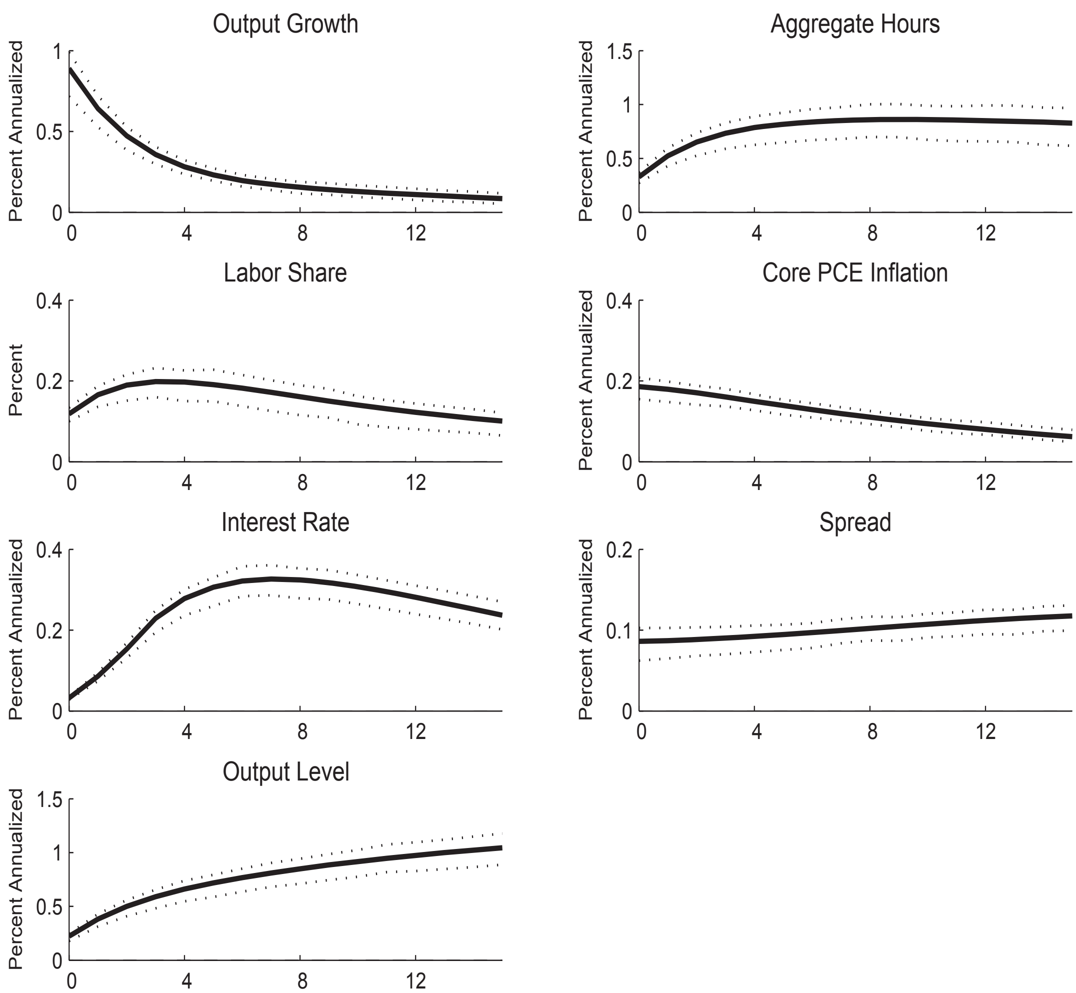

Figure 10: Responses to a TFP Shock

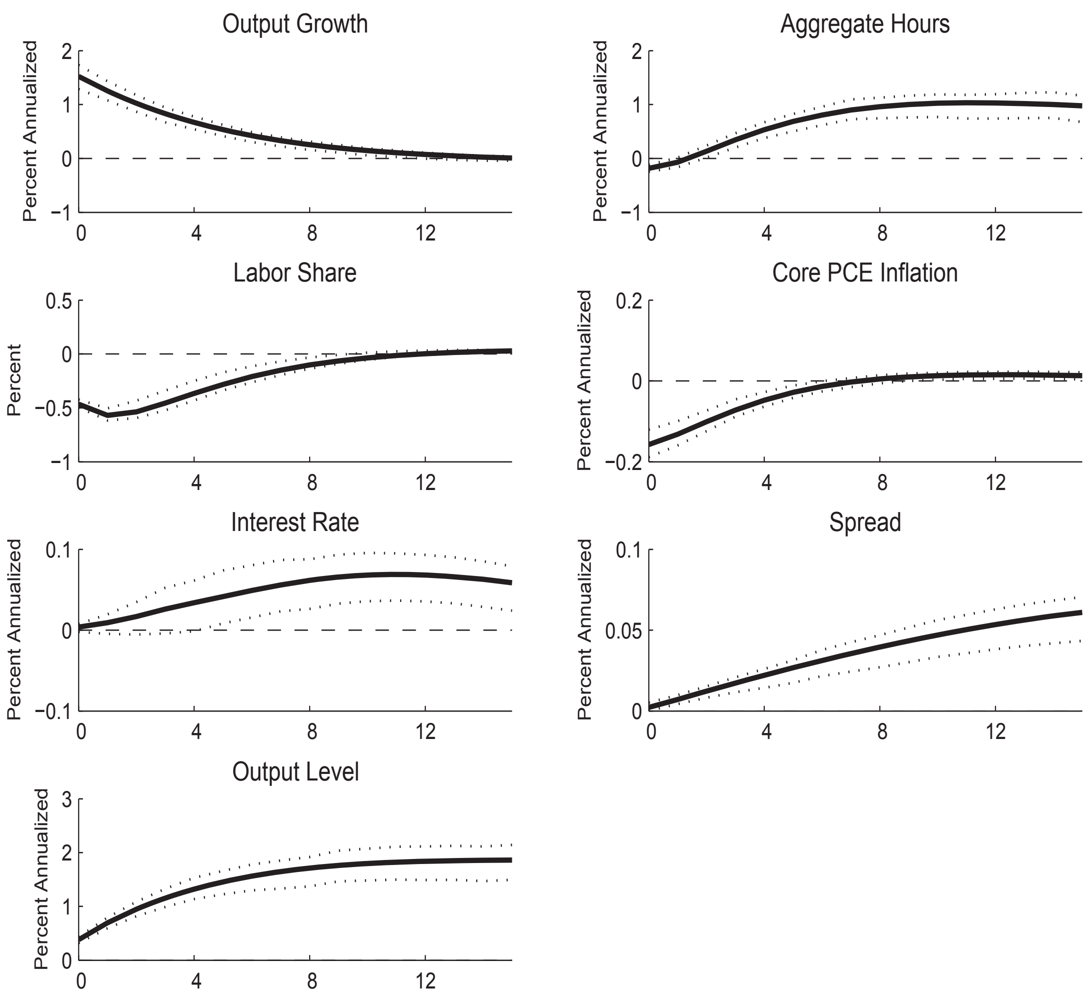

Figure 11: Responses to a Mark-up Shock

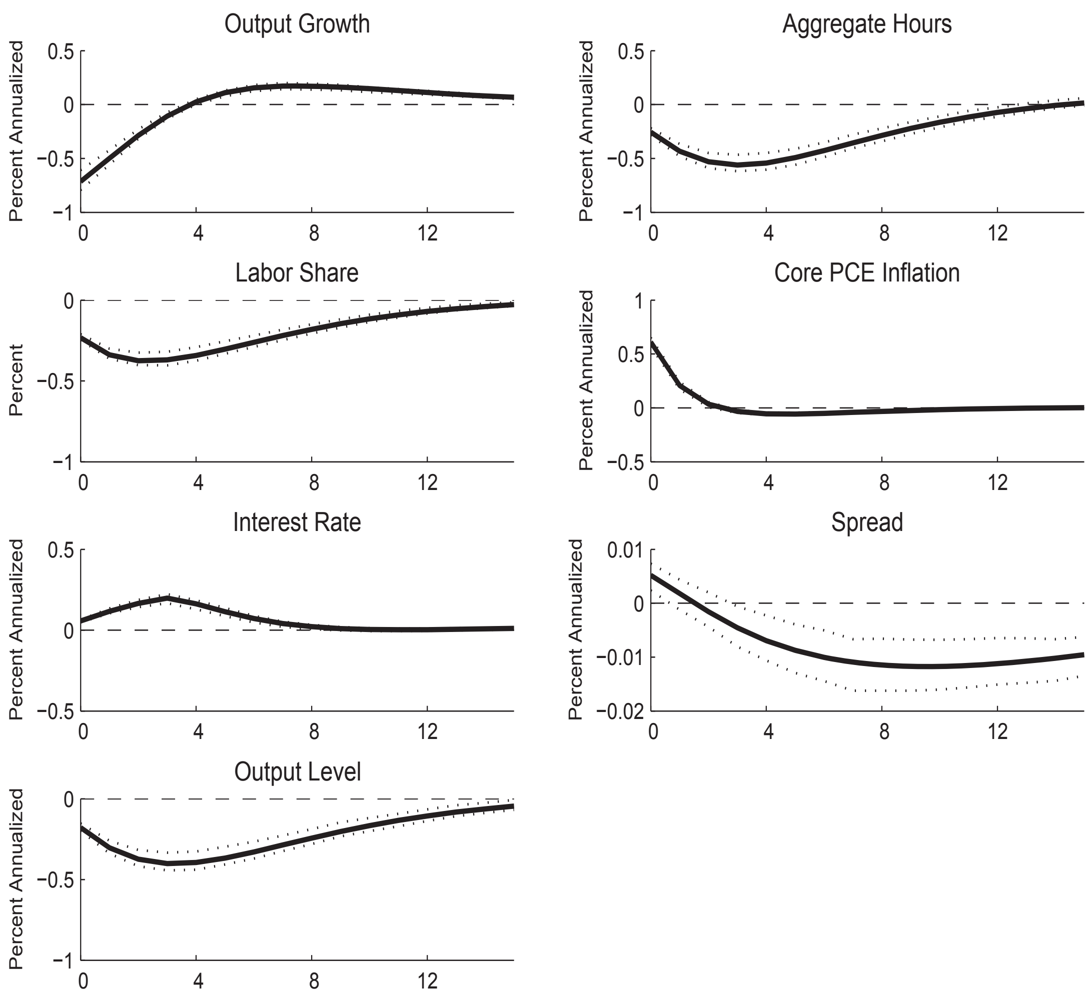

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Figure 12: Responses to a Monetary Policy Shock

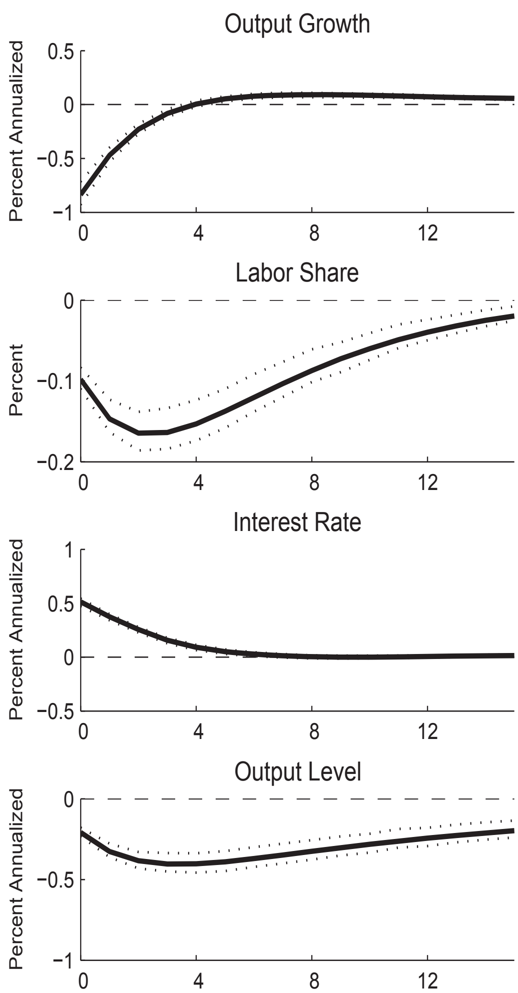

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Figure 13: Responses to a Labor Supply Shock

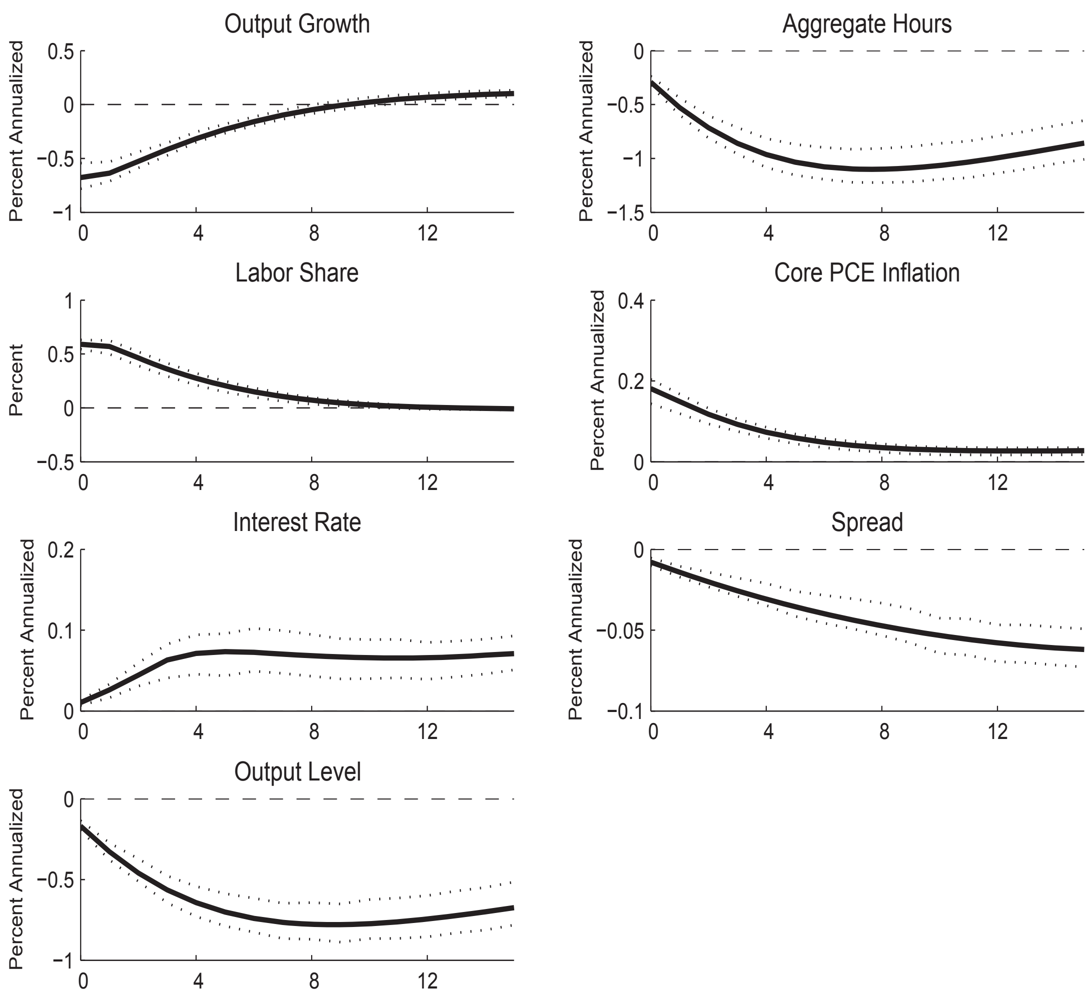

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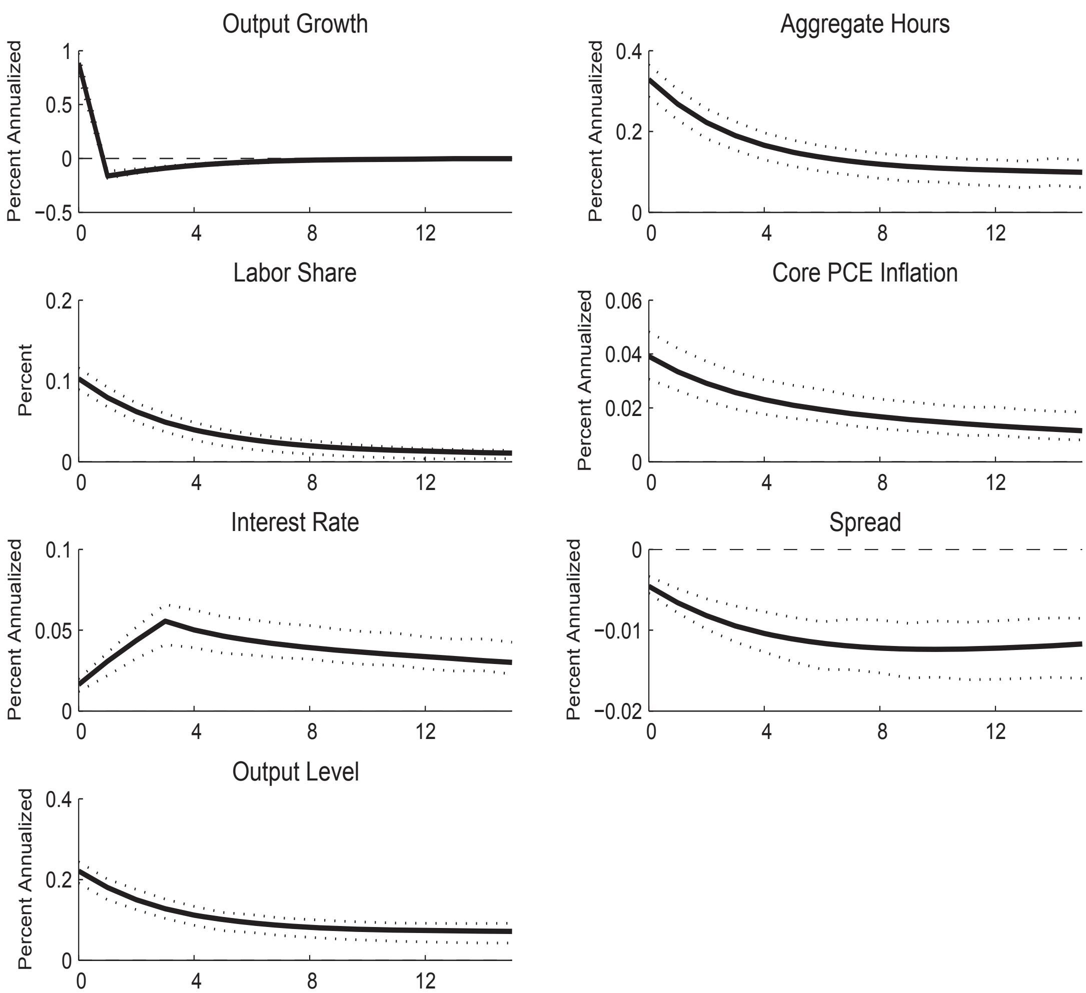
Figure 14: Responses to a Government Spending Shock



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References

[1]

[2] **Bernanke, Ben, Mark Gertler and Simon Gilchrist**, "The Financial Accelerator in a Quantitative Business Cycle Framework," in J.B. Taylor and M. Woodford, eds., Handbook of Macroeconomics, vol. 1C, Amsterdam: North-Holland, 1999.

[3] **Calvo, Guillermo**, "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 1983, *12*, 383–398.

[4] **Christiano, Lawrence, Martin Eichenbaum, and Charles Evans**, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 2005, *113*, 1–45.

[5] **Christiano, Lawrence, Roberto Motto, and Massimo Rostagno**, "Financial Factors in Economic Fluctuations," Unpublished, 2009.

[6] **Del Negro, Marco, Stefano Eusepi, Marc Giannoni, Argia Sbordone, Matthew Cocci, Raiden Hasegawa, and M. Henry Linder**, "The FRBNY DSGE Model," *Federal Reserve Bank of New York Staff Reports*, Number 647.

[7] **Del Negro, Marco and Schorfheide, Frank**, "DSGE Model-Based Forecasting," *Handbook of Economic Forecasting, Volume 2*, 2012.

[8] **Laseen, Stefan and Lars E. O. Svensson**, "Anticipated Alternative Instrument-Rate Paths in Policy Simulations," NBER Working Paper No. w14902, 2009.

[9] **Smets, Frank and Raphael Wouters**, "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 2007, *97* (3), 586 – 606.

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Detailed Philadelphia (PRISM) Forecast Overview

September 2014

Keith Sill

Forecast Summary

The FRB Philadelphia DSGE model denoted PRISM, projects that real GDP growth will run at a fairly strong pace over the forecast horizon with real output growth peaking at about 3.8 percent in early 2015. Core PCE inflation is projected to be contained at below 2 percent through 2017. For this forecast round, we have implemented the assumption that the forecasted federal funds rate is pinned down by current futures market projections through mid-2015. The funds rate is unconstrained beginning in 2015Q3, and rises to about 1.6 percent in 2015Q4. Many of the model's variables continue to be well below their steady-state values. In particular, consumption, investment, and the capital stock are low relative to steady state, and absent any shocks, the model would predict a rapid recovery. These state variables have been below steady state since the end of the recession. The relatively slow recovery to date and the low inflation that has recently characterized U.S. economic activity require the presence of shocks to offset the strength of the model's internal propagation channels.

The Current Forecast and Shock Identification

The PRISM model is an estimated New Keynesian DSGE model with sticky wages, sticky prices, investment adjustment costs, and habit persistence. The model is similar to the Smets & Wouters 2007 model and is described more fully in Schorfheide, Sill, and Kryshko 2010. Unlike in that paper though, we estimate PRISM directly on core PCE inflation rather than projecting core inflation as a non-modeled variable. Details on the model and its estimation are available in a Technical Appendix that was distributed for the June 2011 FOMC meeting or is available on request.

The current forecasts for real GDP growth, core PCE inflation, and the federal funds rate are shown in Figures 1a-1c along with the 68 percent probability coverage intervals. The forecast uses data through 2014Q2 supplemented by a 2014Q3 nowcast based on the latest Macroeconomic Advisers forecast. For example, the model takes 2014Q3 output growth of 3.1 percent as given and the projection begins with 2014Q4. PRISM anticipates that growth accelerate to about 3.8 percent by early 2015. Output growth then tapers off slightly over the remainder of the forecast horizon to reach a pace of about 3.5 percent at the end of 2017. Overall, the output growth forecast for this round is a bit weaker compared with June projection. While output growth is fairly robust, core PCE inflation stays contained at below 2 percent through the forecast horizon. Based on the 68 percent coverage interval, the model sees a minimal chance of deflation or recession (measured as negative quarters of real GDP growth) over the next 3 years. The federal funds rate is constrained near the zero bound through mid-2015. Thereafter, the model dynamics take over and the funds rate rises gradually to 2.9 percent in 2016Q4 and 3.4 percent in 2017Q4. This path is similar to the June projection.

The key factors driving the projection are shown in the forecast shock decompositions (Figures 2a-2e) and the smoothed estimates of the model's primary shocks (shown in Figure 3, where they are normalized by standard deviation). The primary shocks driving above-trend real output growth over the next 3 years are labor supply shocks (labeled Labor) and marginal efficiency of investment shocks (labeled MEI). The model attributes the weak reading on real GDP growth in 2014Q1 to negative shocks to government spending (which includes net exports), TFP, and investment. Government spending shocks reverse quickly in the model and contribute to above-trend growth going forward. Negative TFP shocks unwind more slowly, and provide a modest drag on output growth over the next five quarters or so. Over the course of the recession and recovery PRISM estimated a sequence of large positive shocks to leisure (negative shocks to labor supply) that have a persistent effect on hours worked and so pushed hours well below steady state. As these shocks unwind hours worked rebounds strongly over the forecast horizon and so leads to higher output growth.

As seen in Figure 3, the model estimates a sequence of largely negative discount factor shocks since 2008. All else equal, these shocks push down current consumption and push up investment, with the effect being very persistent. Consequently, the de-trended level of consumption (nondurables + services) remains below the model's estimated steady state at this point. As these shocks wane over the projection period, consumption growth runs at an average pace of about 2.8 percent over the next three years. The model attributes the recent strength in investment growth (gross private domestic + durable goods consumption) to positive MEI shocks that are projected to unwind slowly over the forecast horizon (see Figure 3). Consequently, the principal shocks driving strong investment growth over the forecast horizon are efficiency of investment shocks with an additional boost from labor shocks. To some extent offsetting these factors are financial shocks: the unwinding of the discount factor shocks that contributed positively to investment growth over 2009-2011 leads to a downward pull on investment growth over the next three years. Investment growth runs at about a 7.5 percent pace in 2015 easing back to about a 3 percent pace in 2017.

The forecast for core PCE inflation is largely a story of upward pressure from the unwinding of negative labor supply shocks and MEI shocks being offset by downward pressure from the waning of discount factor shocks. Negative discount factor shocks have a strong and persistent negative effect on marginal cost and inflation in the estimated model. Compared, for example, to a negative MEI shock that lowers real output growth by 1 percent, a negative discount factor shock that lowers real output growth by 1 percent leads to a 3 times larger drop in inflation that is more persistent. The negative discount factor shock leads to capital deepening and higher labor productivity. Consequently, marginal cost and inflation fall. The negative effect of discount factor shocks on inflation is estimated to have been quite significant since the end of 2008. As these shocks unwind over the projection period there is a decreasing, but still substantial, downward effect on inflation over the next three years (these shocks have a very persistent effect on inflation).

Partly offsetting the downward pressure on inflation from discount factor shocks is the upward pressure coming from the unwinding of negative labor supply shocks. Labor supply shocks that push down aggregate hours also serve to put upward pressure on the real wage and hence marginal cost. The effect is persistent -- as the labor supply shocks unwind over the forecast horizon they exert a waning upward push to inflation. On balance the effect of these opposing forces is to keep inflation below 2 percent through the forecast horizon.

The Unconditional Forecast

Pinning down the federal funds rate at current market expectations through mid-2015 (using fully anticipated monetary policy shocks) has a fairly small impact on the PRISM forecast for output growth and inflation. Figures 4a-c show the forecast and shock decompositions for the unconditional forecast (ie, a forecast that does not constrain the funds rate path). The forecasted path for real GDP growth is marginally weaker compared the conditional forecast for the next 3 years under a less-accommodative monetary policy. The projection for core PCE inflation is a bit stronger than in the conditional forecast, even though the federal funds rate begins to rise immediately, reaching about 2.8 percent by the end of 2015 and 3.6 percent by the end of 2016. Thus the inflation forecast is somewhat stronger if the funds rate is not constrained at the ZLB through mid-2014.

The fact that the forecast with a more accommodative policy has a weaker inflation path and only slightly stronger output growth is counter intuitive. It is the case in the PRISM model that an anticipated easing of monetary policy in the future does lead to an immediate jump in current period output and inflation – the economy strengthens with the easier policy. Compared to the unconditional forecast, an anticipated easing of monetary policy leads to a stronger economy and higher inflation today.

Why then the weaker inflation projection in PRISM under the funds-rate-constrained policy? The reason is that history is locked down in the model. For example, output growth in 2014Q3 is given at 3.1 percent and inflation is 2 percent in both the unconditional and conditional forecasts since it is treated as historical data (recall that we use a nowcast for 2014Q3 as data to update the March projection). An easing of future monetary policy, by construction, cannot change 2014Q3 output growth or inflation – or indeed their history. Consequently, the model re-weights shocks so that negative TFP, discount factor, and MEI shocks offset the stimulus from anticipated easier monetary policy in order to keep the history of output growth and inflation unchanged. The persistence of the re-weighted TFP, discount factor, and MEI shocks then shows through as the model projection unfolds. If we were to instead allow the PRISM model variables that map into data observations to immediately adjust in response to an anticipated easing of policy, the economic forecast would look significantly stronger.

As implemented though, leaving the funds rate unconstrained in the forecast shifts the historical shock decomposition to give an expected path for output growth that is broadly similar and inflation that is somewhat higher compared to the conditional forecast. With inflation running at about target and strong output growth, PRISM forecasts that the funds rate should begin rising immediately, reaching 4 percent by the end of 2017 -- roughly 55 basis points above the constrained path federal funds rate at that point.

References

Schorfheide, Frank, Keith Sill, and Maxym Kryshko. 2010. “DSGE model-based forecasting of non-modelled variables.” *International Journal of Forecasting*, 26(2): 348-373.

Smets, Frank, and Rafael Wouters. 2007. “Shocks and Frictions in U.S. Business Cycles: A Bayesian DSGE Approach.” *American Economic Review*, 97(3): 586-606.

Figure 1a

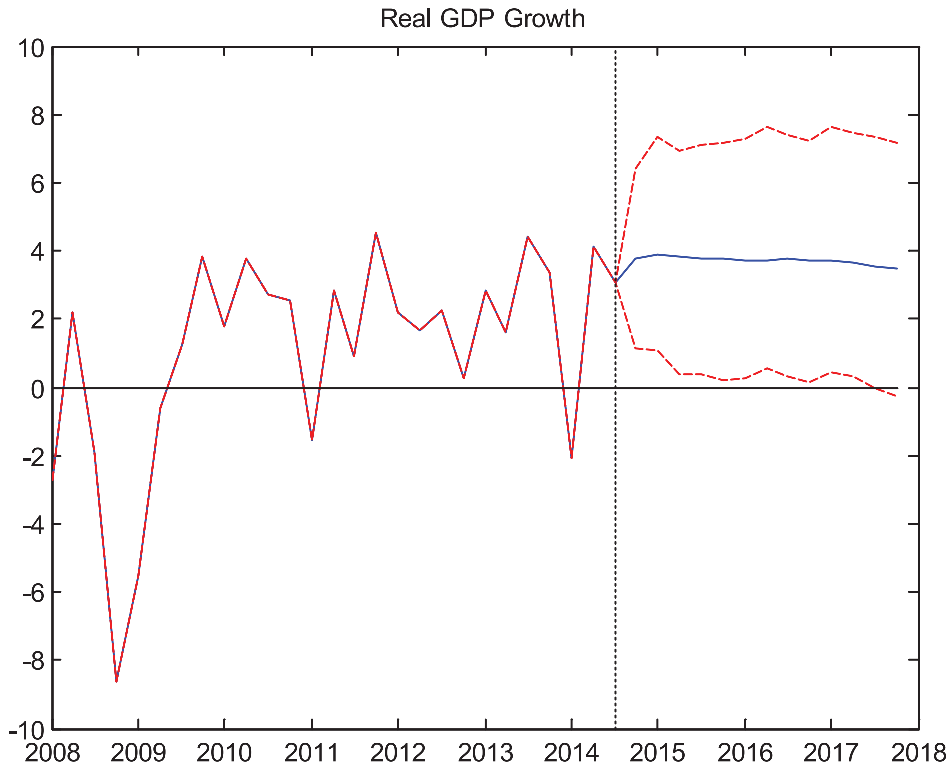

Real GDP Growth
10
8
6
4
2
0
-2
-4
-6
-8
-10
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

Figure 1b

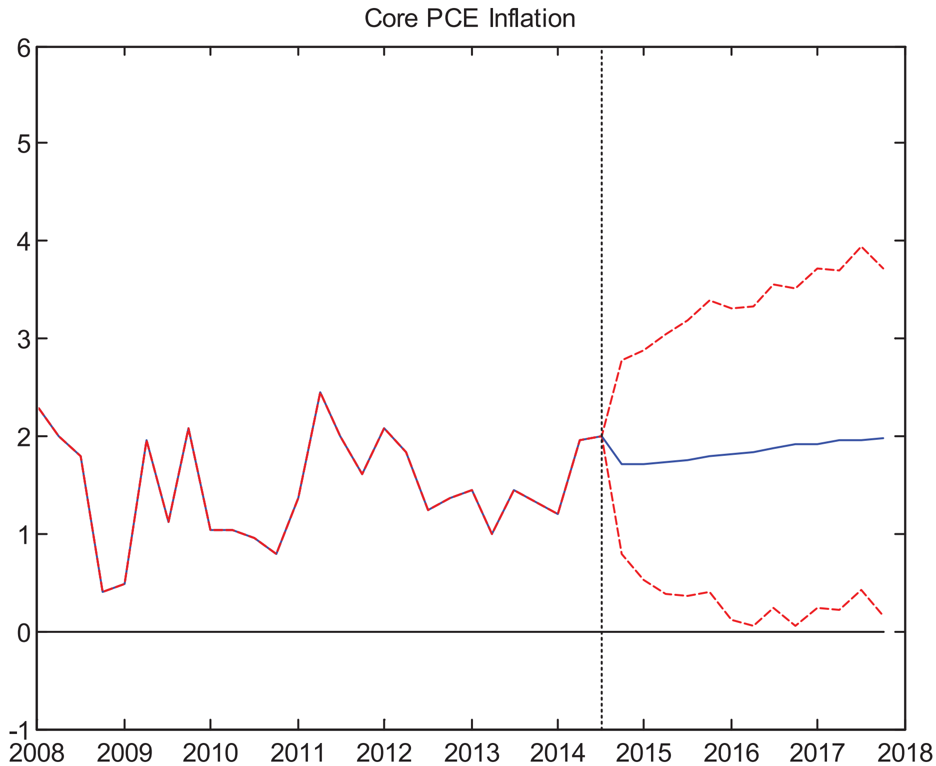

Core PCE Inflation
6
5
4
3
2
1
0
-1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

Figure 1c

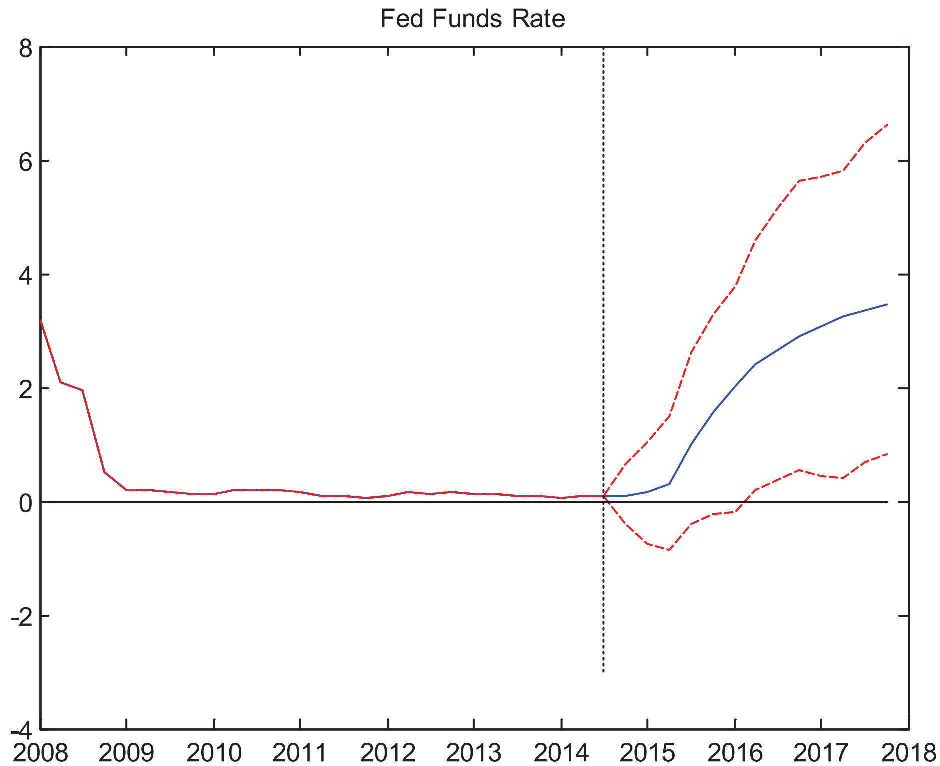
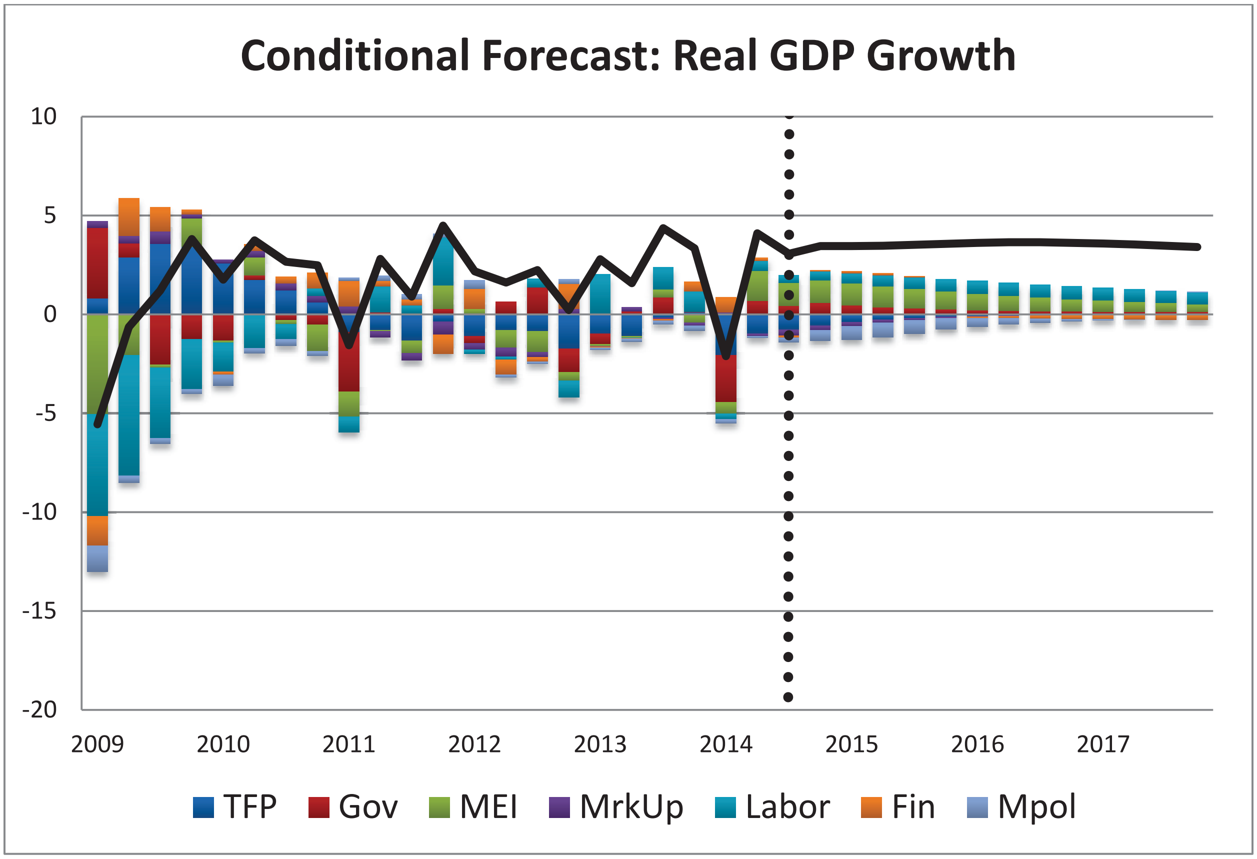

Fed Funds Rate
8
6
4
2
0
-2
-4
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

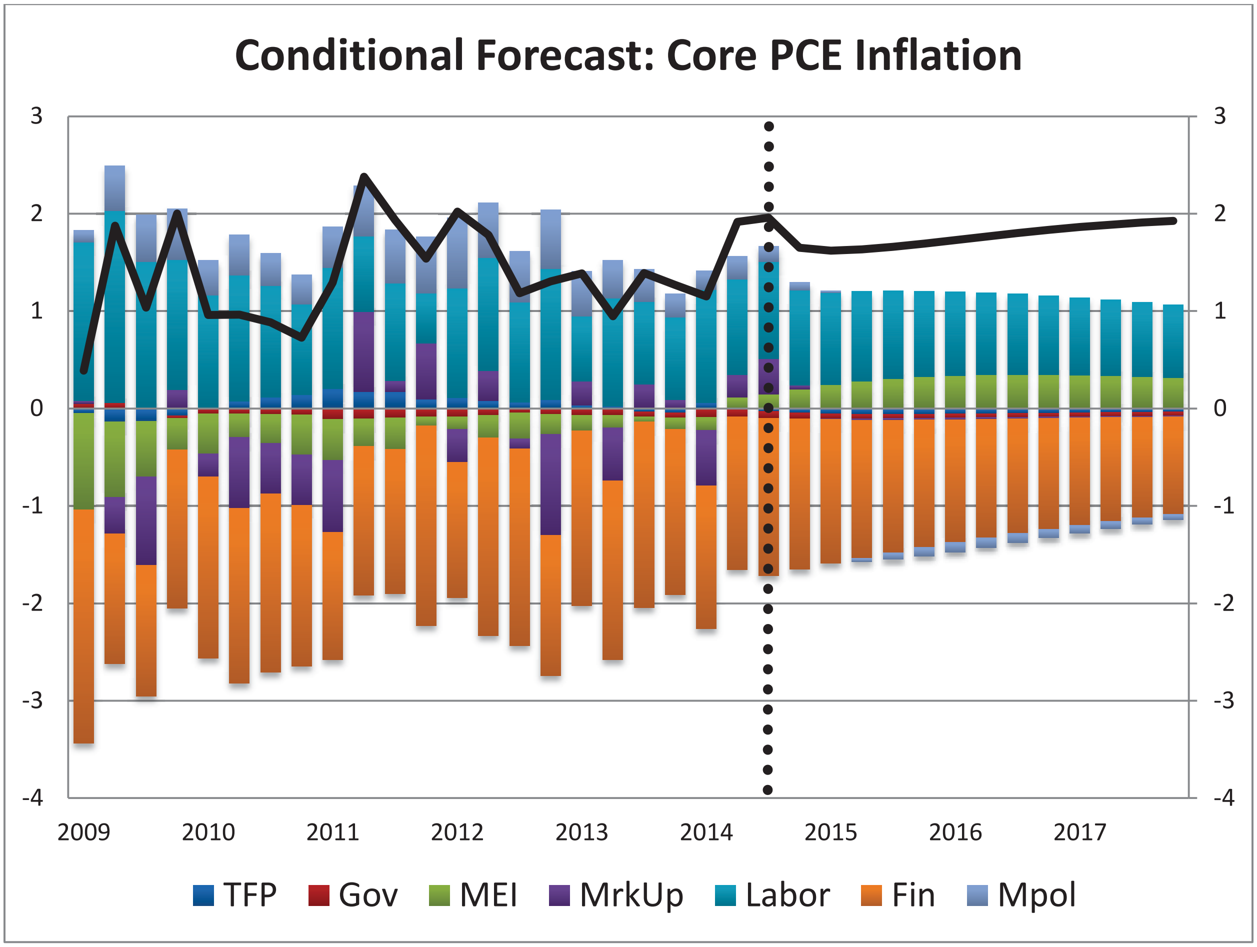
Figure 2a
Conditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

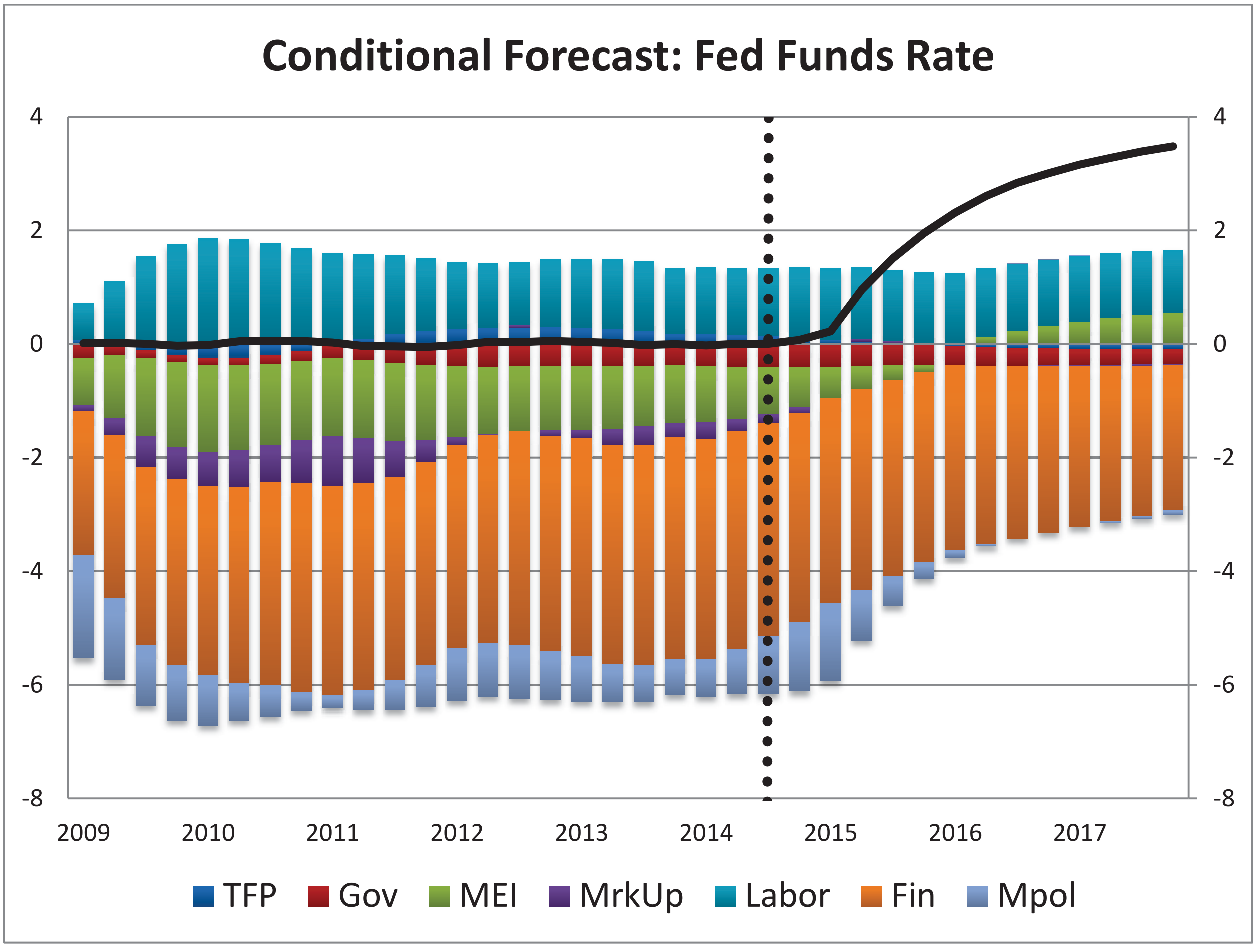
Figure 2b
Conditional Forecast



shocks:

TFP: Total factor productivity growth shock
Gov: Government spending shock
MEI: Marginal efficiency of investment shock
MrkUp: Price markup shock
Labor: Labor supply shock
Fin: Discount factor shock
Mpol: Monetary policy shock

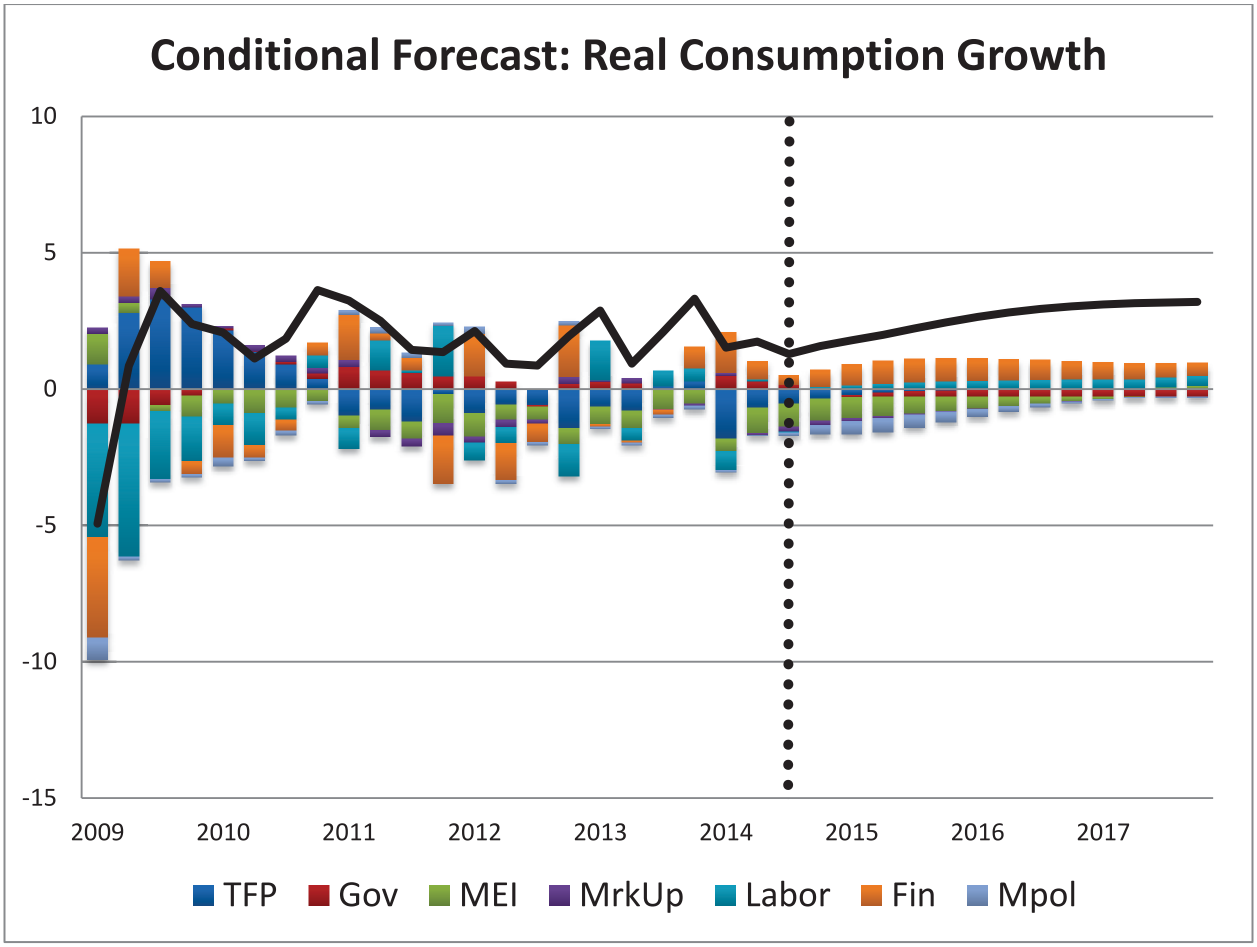
Figure 2c
Conditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

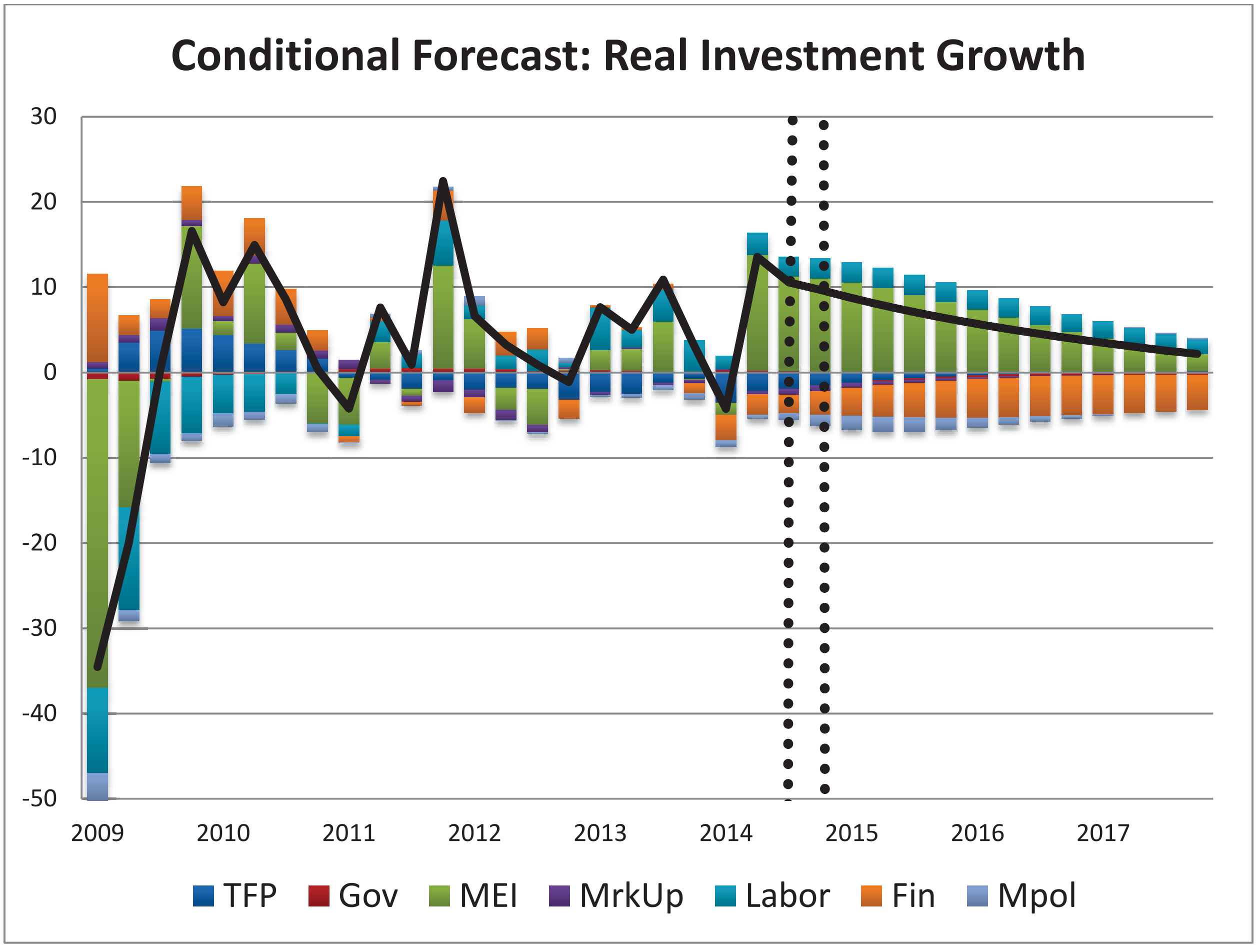
Figure 2d
Conditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

Figure 2e
Conditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

Figure 3
Smoothed Shock Estimates for Conditional Forecast Model
(normalized by standard deviation)

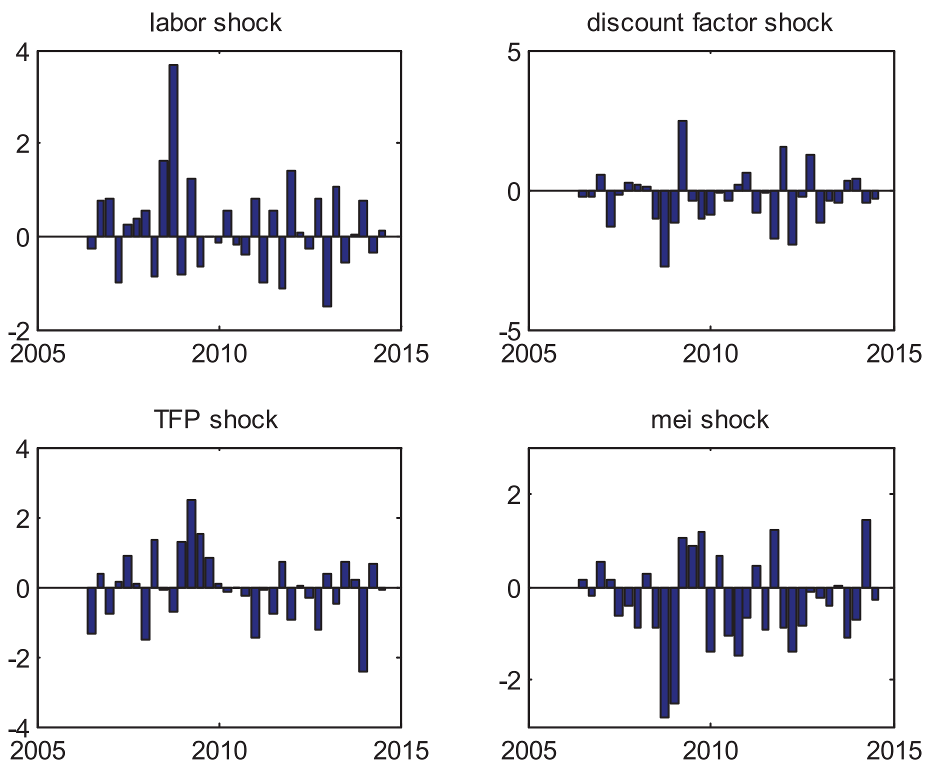
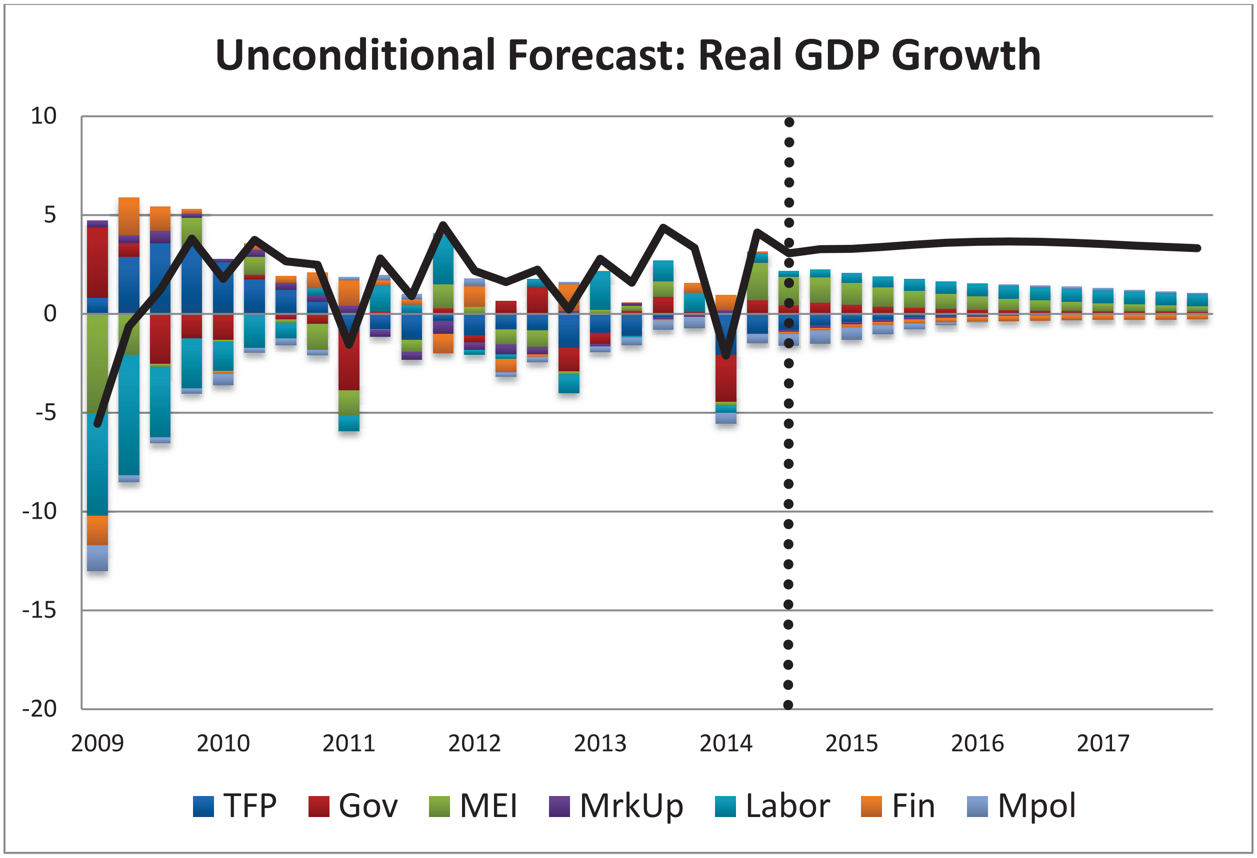


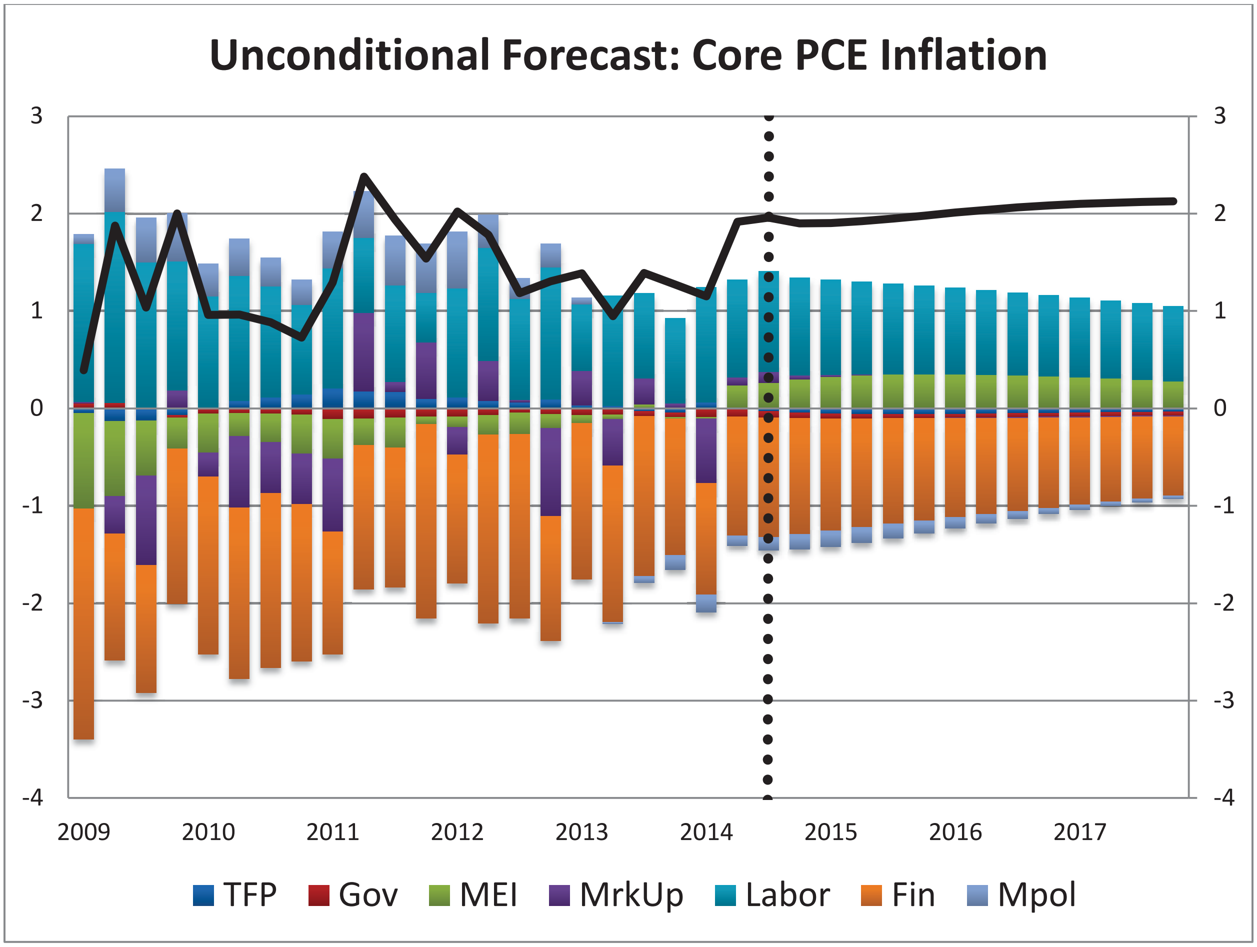
Figure 4a
Unconditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

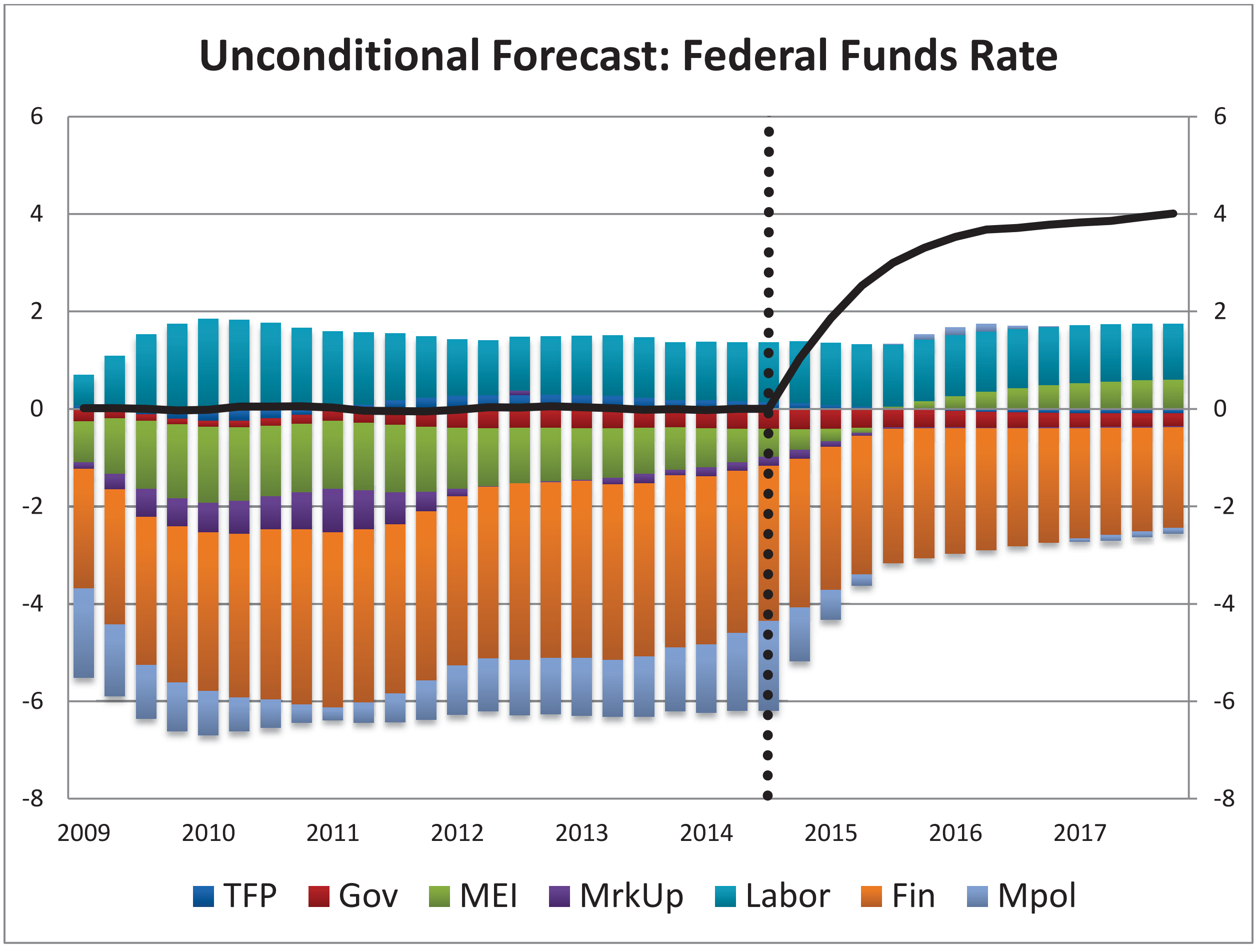
Figure 4b
Unconditional Forecast



shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

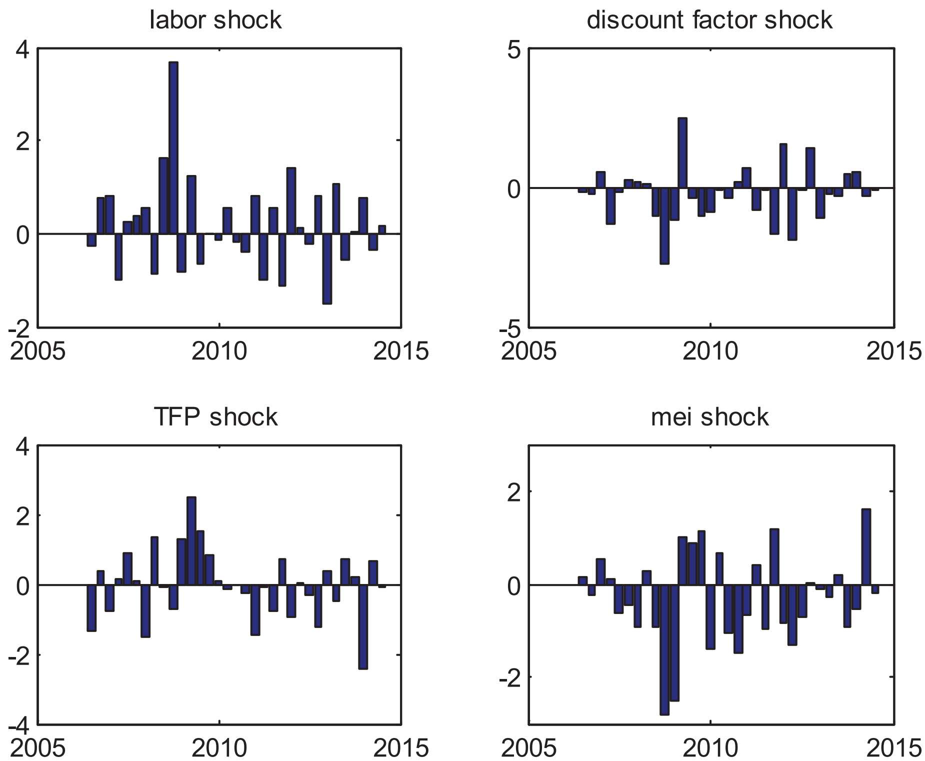
Figure 4c
Unconditional Forecast



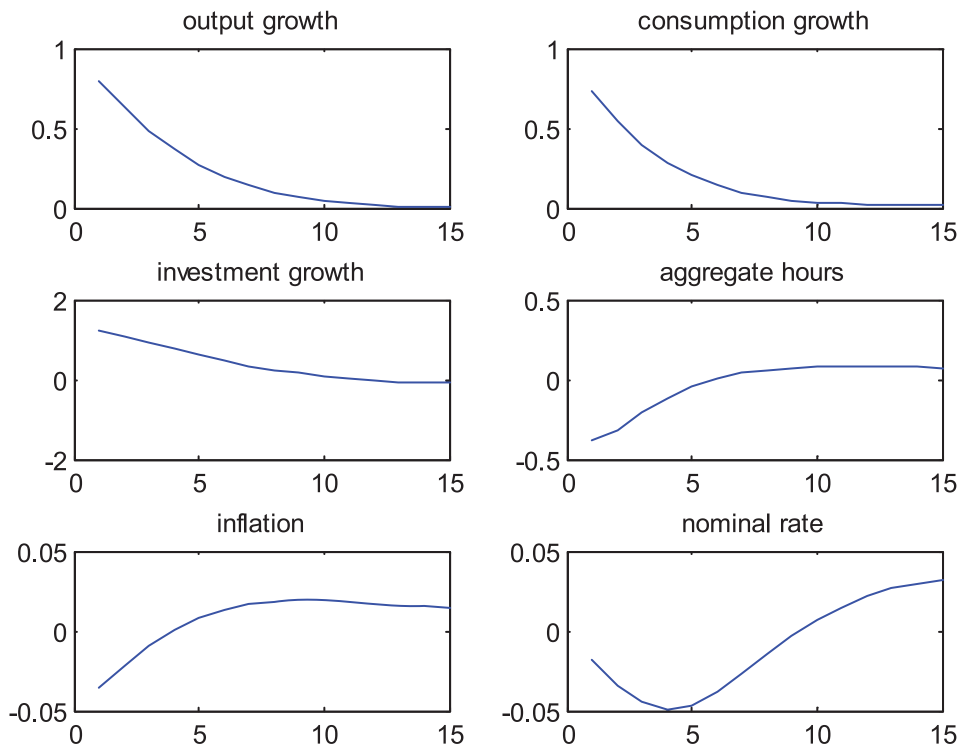
shocks:

TFP:	Total factor productivity growth shock
Gov:	Government spending shock
MEI:	Marginal efficiency of investment shock
MrkUp:	Price markup shock
Labor:	Labor supply shock
Fin:	Discount factor shock
Mpol:	Monetary policy shock

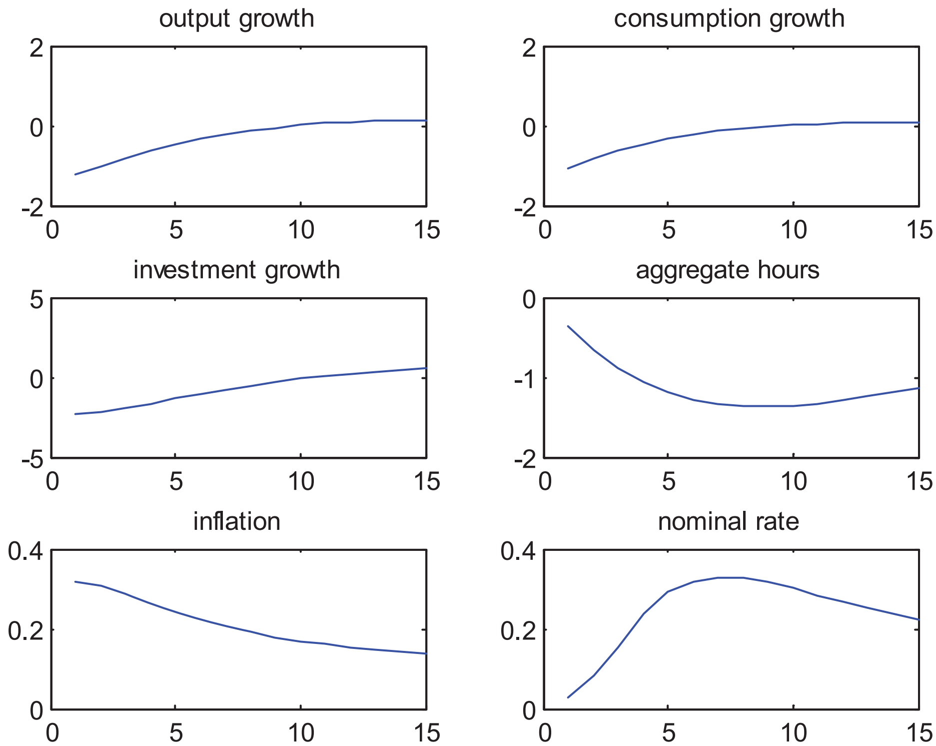
Figure 5
Smoothed Shock Estimates from Unconstrained Forecast Model
(normalized by standard deviation)



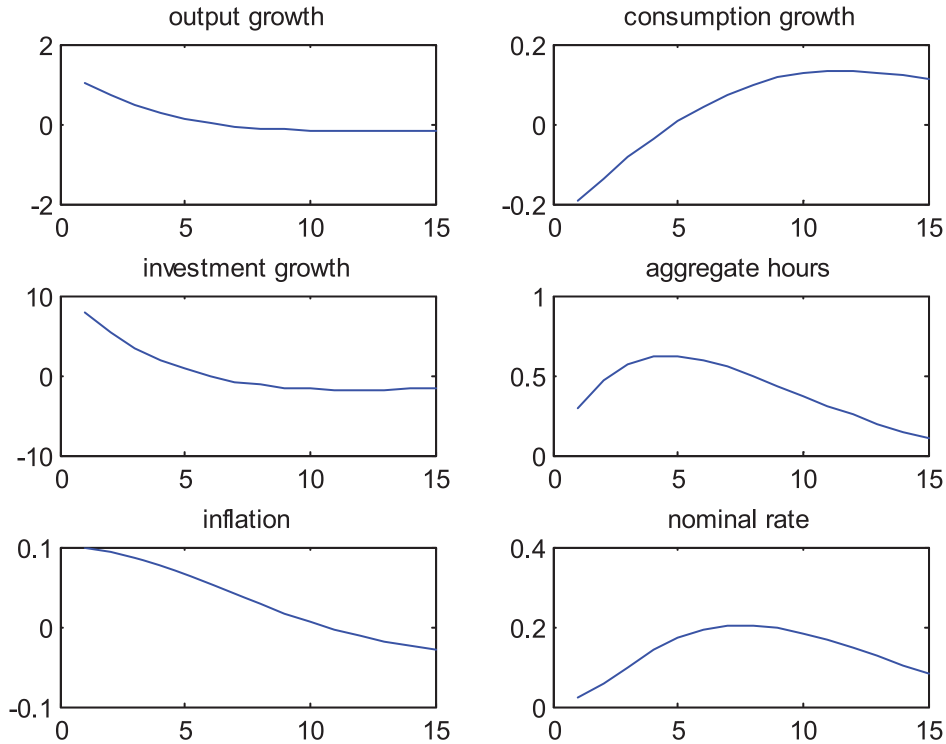
Impulse Responses to TFP shock



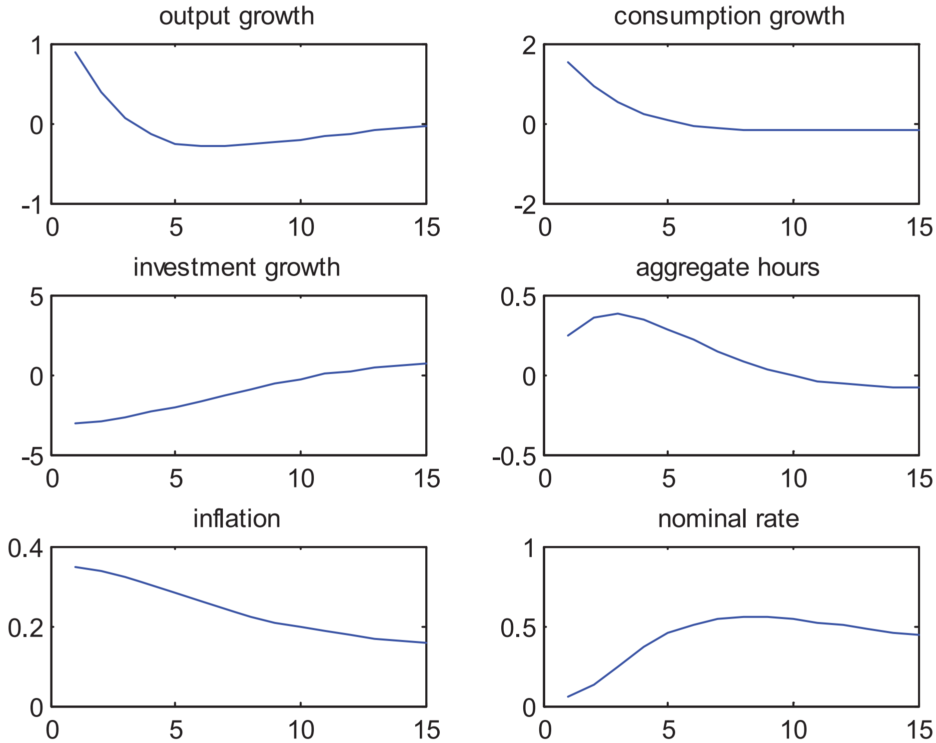
Impulse Response to Leisure Shock



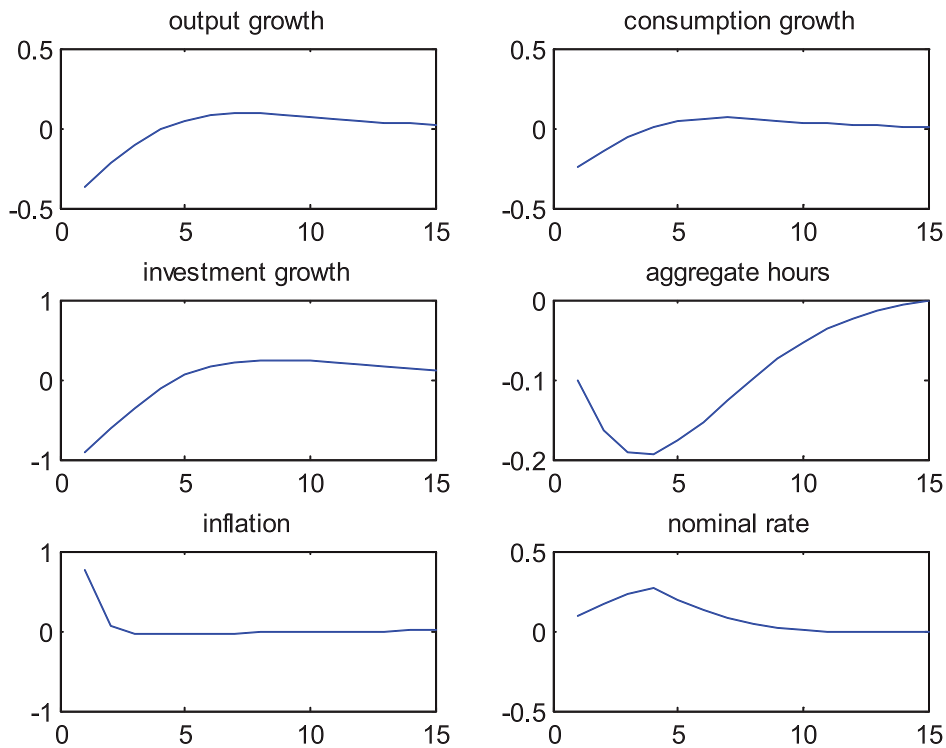
Impulse Responses to MEI Shock



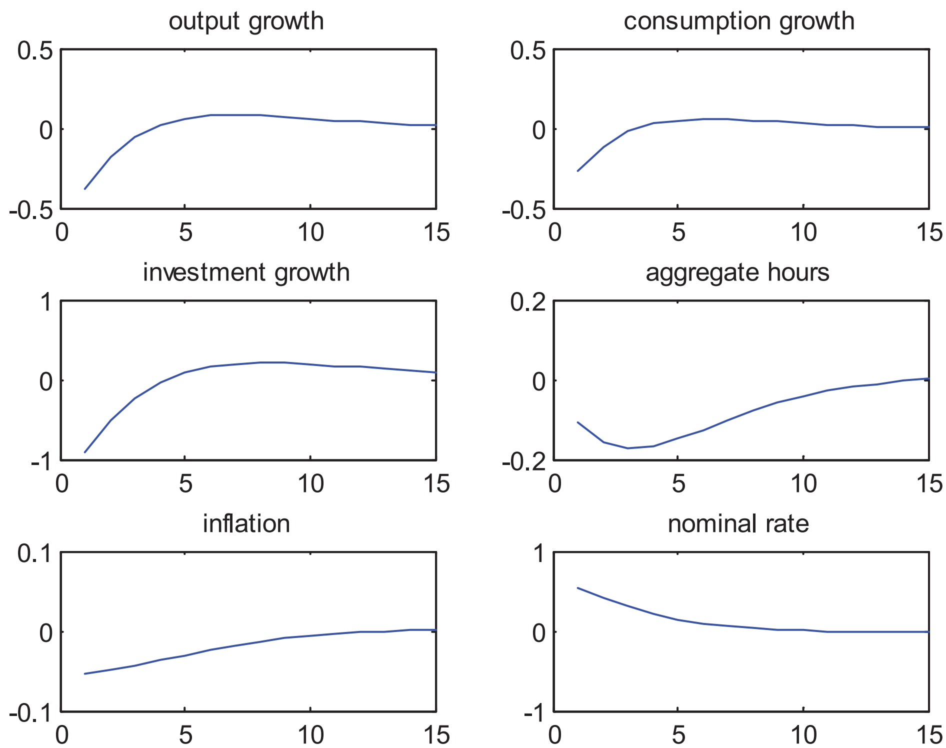
Impulse Responses to Financial Shock



Impulse Responses to Price Markup Shock



Impulse Responses to Unanticipated Monetary Policy Shock



Impulse Responses to Govt Spending Shock