BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

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Date: December 4, 2015

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.

System DSGE Project: Research Directors Drafts

December 4, 2015

The Current Outlook in EDO:

December 2015 FOMC Meeting

Class II – Restricted FR

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December 4, 2015

1 The EDO Forecast from 2015 to 2018

The EDO model forecast conditions on data through 2015:Q3 and a preliminary Tealbook forecast for the fourth quarter of 2015. Real GDP growth is projected to hover slightly below its trend of 3 percent from 2016 until the end of the forecast period. Inflation increases gradually over the next year from the current level of 1.3 percent, reaching the Committee's 2 percent objective by early 2017. The federal funds rate lifts appreciably above its effective lower bound in the first quarter of 2016, surpassing 3 percent by early 2018.

The model predicts a relatively quick rebound in activity over 2016, discounting recent episodes of weak output growth on the basis of consistent improvements in the labor market. Growth is restrained, however, by the effects of extremely persistent adverse movements in the capital-specific risk premium, inferred from the lackluster growth of investment in spite of low real interest rates, as well as by the waning effects of past monetary stimulus.

Largely in reaction to the still-low levels of the employment-to-population ratio, the model estimates an output gap of -2 percent at the end of 2015. With growth slightly below trend, the output gap closes very slowly and remains at -0.8 percent by the end of 2018. The natural rate of interest in 2015:Q4 is 0.8 percent, $1\frac{1}{4}$ percent below its steady-state value of 2.1 percent. The natural rate is held down in the current quarter by the capital risk-premium shocks as well as by an elevated aggregate risk premium. As with the output gap, convergence back to steady state is protracted, with the natural rate reaching only 1.2 percent at the end of the projection period.

We made several changes to the EDO model in order to improve its accounting of labor market dynamics. In addition, we no longer condition on 12 quarters of data on the expected path of the federal funds rate from futures markets. Instead, we use the estimated interest feedback rule. As a

*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.

result of these changes, the average growth rate of output in 2016 is over $\frac{3}{4}$ of a percent higher than under the previous version of the model. In addition, the federal funds rate path is steeper, rising on average about 1.1 percent from the path projected in September. Given that the funds rate is no longer constrained to be as low as the path expected by financial markets, model dynamics are not restricted to deliver a weak economic outlook consistent with an expected slow path for the funds rate. Thus, the EDO model projects that GDP growth and the funds rate converge to their steady-state values more rapidly than before.

To separate the effects of news since September from the effects of changes in the model, we generate a forecast using the current model and conditioning on data available at the close of the September Tealbook. The output data received since September has been weaker than the current model expected. Consequently, keeping the model the same, the forecast for GDP growth in 2016 and 2017 have been revised down by $\frac{1}{4}$ of a percent, accounted for by a more adverse path for the capital risk premium.

2 An Overview of Key Model Features

Figure 3 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.[1]

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 (for example, 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 nondurable goods and nonhousing services, consumer durable goods, residential investment, and nonresidential investment. The boxes surrounding the producers in the figure illustrate how we structure the sources of each demand category. Consumer nondurable goods and services are sold directly to households; consumer durable goods, residential capital goods, and nonresidential capital goods are intermediated through capital-goods intermediaries (owned by the households), who then rent these capital stocks to households. Consumer nondurable 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 nonresidential capital goods are purchased (by consumer durable and residential capital goods owners, respectively) from the second sector. In addition to consuming the nondurable

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

Figure 1: Recent History and Forecasts

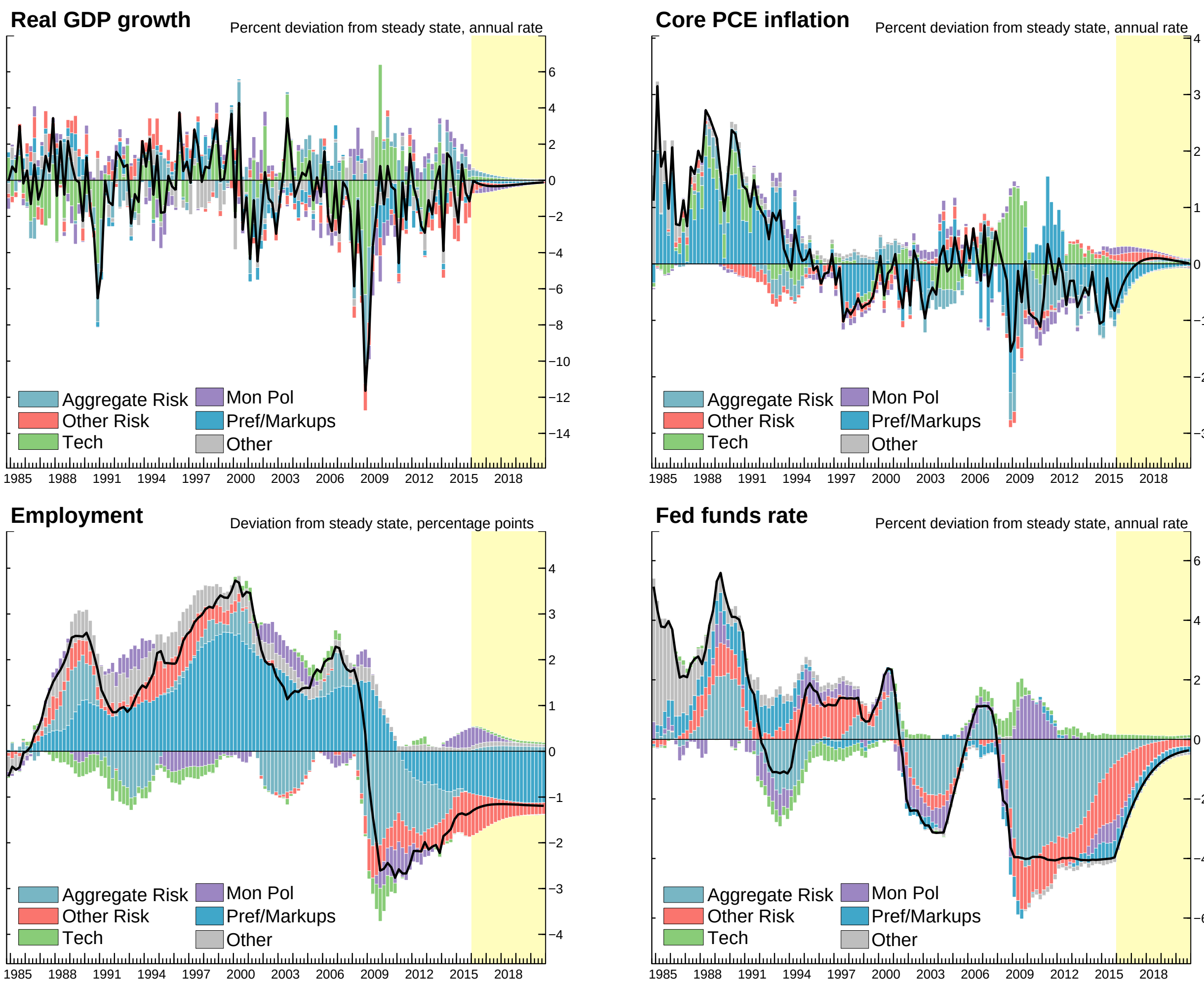


Figure 2: Recent History and Forecasts: Latent Variables

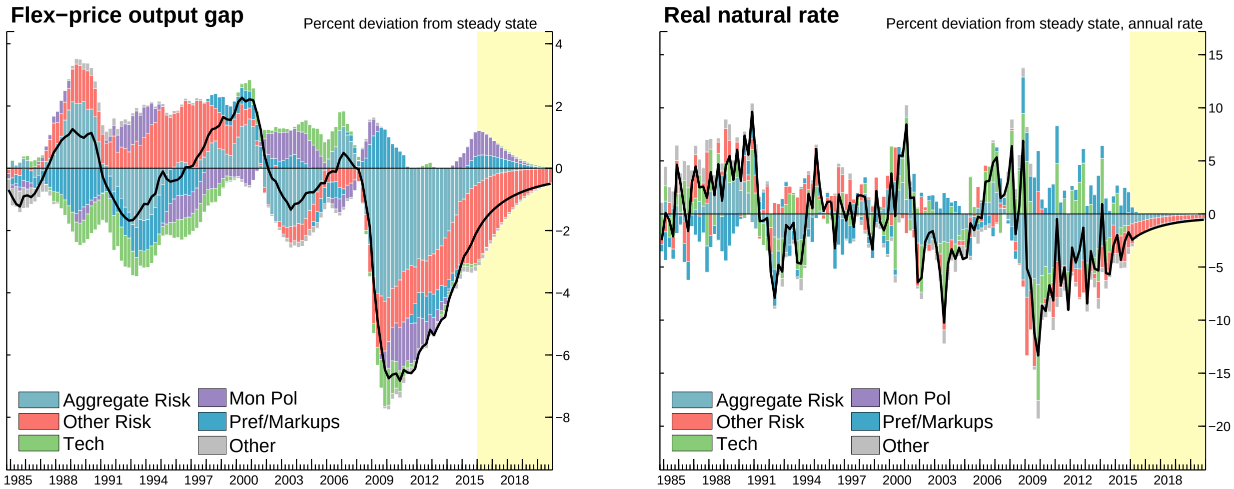
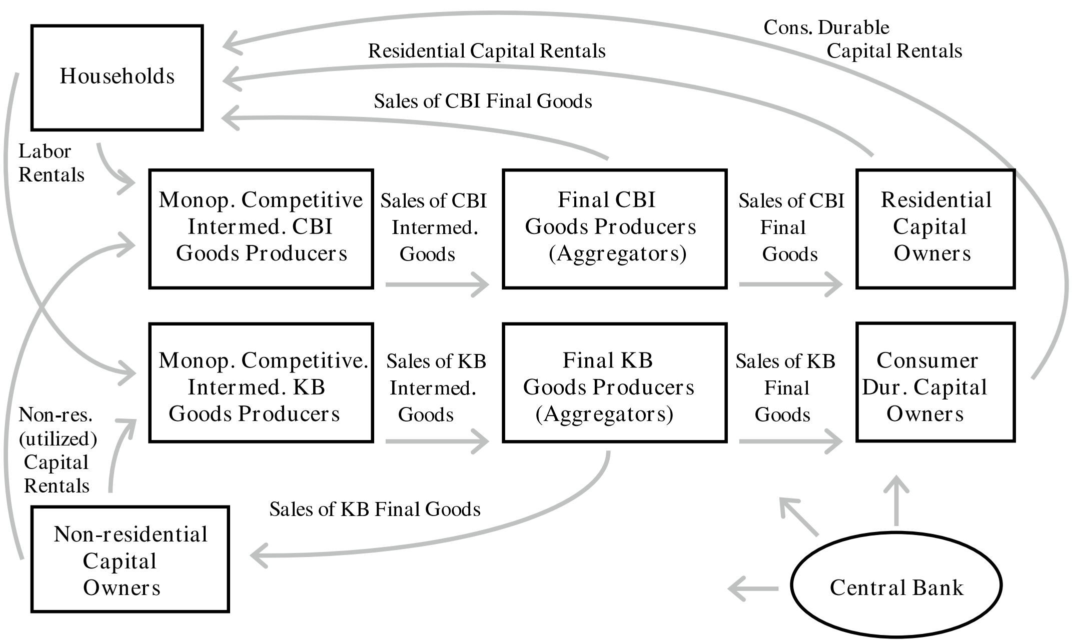


Figure 3: Model Overview



goods and services that they purchase, households supply labor to the intermediate goods-producing firms in both sectors of the economy.

The remainder of this section provides an overview of the main 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 premiums associated with different investment decisions play a central role in the model. These include, first, an aggregate risk premium, or natural rate of interest, shock driving a wedge between the short-term policy rate and the interest rate faced by private decisionmakers (as in Smets and Wouters (2007)) and, second, fluctuations in the discount factor/risk premiums faced by the intermediaries financing household (residential and consumer durable) and business investment.

2.1 Two-sector production structure

It is well known (for example, 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 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 *nonresidential 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 for 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 nonresidential capital used in production, and households value consumer nondurables goods and services, consumer durable goods, and residential capital (for example, 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:

$$\mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \Big\{ \varsigma^{cnn} \ln(E_t^{cnn}(i) - hE_{t-1}^{cnn}(i)) + \varsigma^{cd} \ln(K_t^{cd}(i)) \\ + \varsigma^r \ln(K_t^r(i)) - \Lambda_t^{Lpref} \Theta_t^H \sum_{s=cbi,kb} \int_0^1 \varsigma^{l,s} L_t^s(i)^{\frac{1+\sigma_N}{1+\frac{\sigma_N}{1+\sigma_h}}} di \Big\}, \quad (2)$$

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), Λ_t^{Lpref} represents a labor supply shock, Θ_t is an endogenous preference shifter whose role is to reconcile the existence of a long-run balance growth path with a small short-term wealth effect[2], L^{cbi} and L^{kb} represent the 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). Gali, Smets, and Wouters (2011) state that the introduction of the endogenous preference shifter is key in order to match the joint behavior of the labor force, consumption, and wages over the business cycle.

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 in the early 2000s recession and the most recent downturn. Many other models do not distinguish between developments across these categories of spending.

[2]The endogenous preference shifter is defined as $\Theta_t^H = Z_t \Lambda_t^{cnn}$, where $Z_t = \frac{Z_{t-1}^{1-\nu}}{\Lambda_t^{cnn}}$ and Λ_t^{cnn} is the shadow price of nondurable consumption. The importance of the short-term wealth effect is determined by the parameter $\nu \in (0, 1]$.

2.3 Risk premiums, 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 that have high expected returns in adverse states of the world. However, the behavior 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 modeled in EDO, that 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 premiums leads to sizable substitution across residential, consumer durable, and business investment; for example, an increase in the risk premiums on residential investment leads households to shift away from residential investment and toward 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 premiums.

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, that is, the premium is a shock to the natural rate of interest. Given nominal rigidities, however, the desire for higher risk-free savings must be offset, in part, through a fall in real income, a decline which is distributed across all spending components. Because this response is capable of generating co-movement 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 (for example, 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 premiums fluctuate for endogenous reasons (for example, 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 modeled in EDO. The sector-specific risk premiums in EDO enter the model in much the same way as does the exogenous component of risk premiums 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.[3]

2.4 Labor market dynamics 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 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 additional 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 substitution between leisure and consumption, implying that workers would prefer to work more.

The new preference specification and the incorporation of labor force participation in the information set impose discipline in the overall labor market dynamics of the EDO model. The estimated short-run wealth effect on labor supply is relatively attenuated with respect to previous versions of the EDO model. Therefore, the dynamics of both labor force participation and employment are more aligned with the empirical evidence.

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 the labor market is suitable for discussion of the links between employment 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.

The decline in employment 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 light blue and red bars in figure 1. The role played by these demand factors in explaining the cyclical movements in employment is only determinant during the 1980s and during the Great Recession. As apparent in figure 1, the most relevant drivers of employment in the remaining of the sample are labor supply (preference) and markup shocks as shown by the blue bars.

[3]Specifically, the risk premiums 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.

Specifically, favorable supply developments in the labor market are estimated to have placed upward pressure on employment until 2010; these developments have reversed, and some of the currently low level for employment growth 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 sizable 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 $\bar{R}_t$

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

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 premiums 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

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

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 (for example, 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 markups) 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 13 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 to supply labor. As was apparent in our earlier description of labor market dynamics and in the presentation of the structural drivers below, this shock captures the dynamics of the labor force participation rate in the sample and those of employment. While EDO labels such movements labor supply shocks, an alternative interpretation would describe these as movements in the labor force and employment that reflect structural features not otherwise captured by the model.
- Financial, or intertemporal, shocks: This category consists of shocks to risk premiums. In EDO, variation in risk premiums —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 (for example, 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 2015:Q3. The series are the following:

1. The growth rate of real gross domestic product (ΔGDP);
2. The growth rate of real consumption expenditure on nondurables and services (ΔC);
3. The growth rate of real consumption expenditure on durables (ΔCD);
4. The growth rate of real residential investment expenditure (ΔRes);
5. The growth rate of real business investment expenditure (ΔI);
6. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure (PCE) price index ($\Delta P_{C,total}$);
7. Consumer price inflation, as measured by the growth rate of the PCE price index excluding food and energy prices ($\Delta P_{C,core}$);
8. Inflation for consumer durable goods, as measured by the growth rate of the PCE price index for durable goods (ΔP_{cd});
9. Hours, which equals hours of all persons in the nonfarm business sector from the Bureau of Labor Statistics (H);
10. Civilian employment-population ratio, defined as civilian employment from the Current Population Survey (household survey) divided by the noninstitutional population, age 16 and over (N);
11. Labor force participation rate;
12. 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); and
13. The federal funds rate (R).

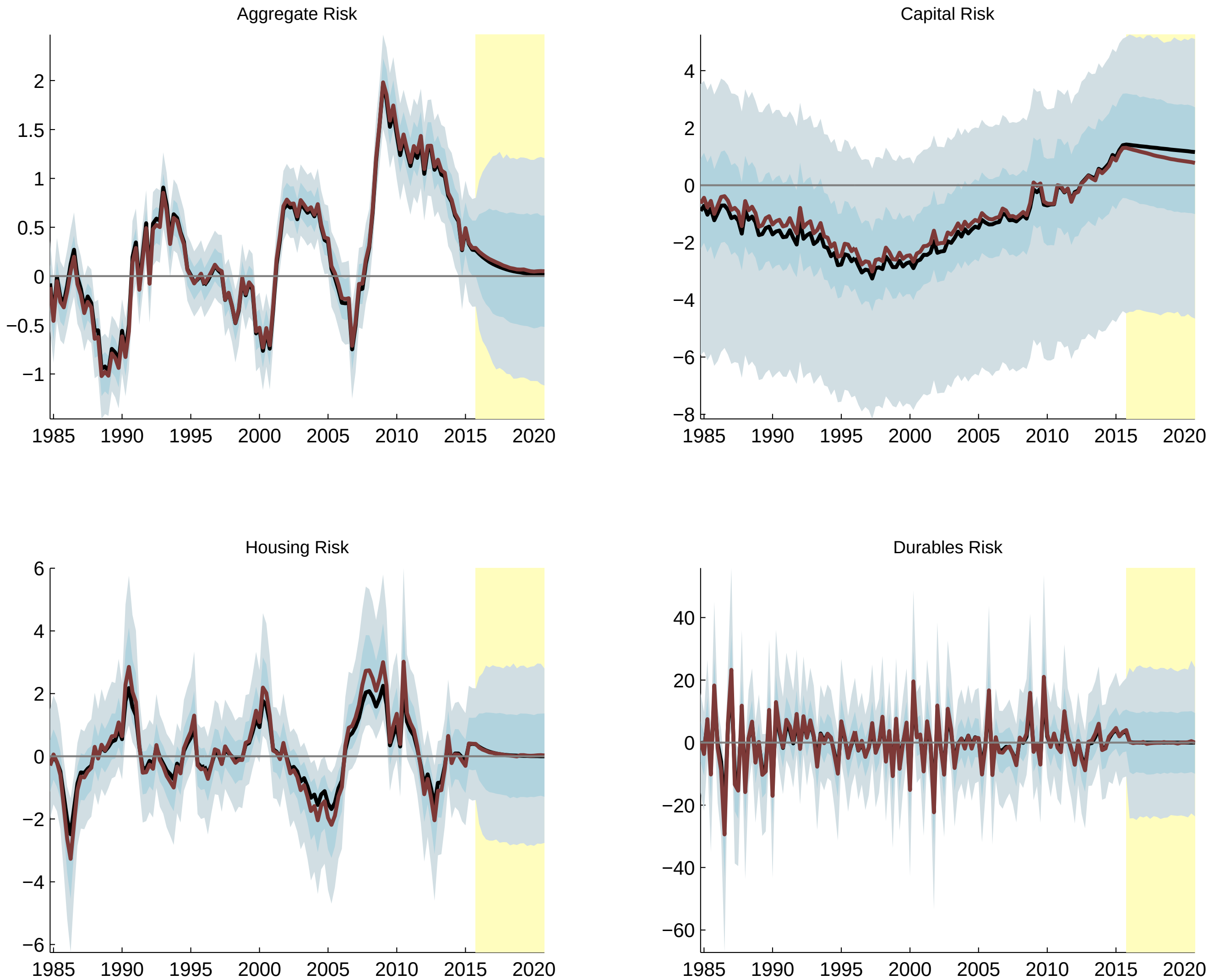
Our implementation adds measurement error processes to the likelihood implied by the model for all of the observed series used in estimation except the short-term nominal interest rate series.

3.2 Estimates of latent variable paths

Figures 4, 5, and 6 report estimates of the model's persistent exogenous fundamentals (for example, risk premiums and autonomous demand). These series have recognizable patterns for those familiar with U.S. economic fluctuations. For example, the risk premiums jump at the end of 2008, reflecting the financial crisis and the model's identification of risk premiums, both economy-wide and for housing, as key drivers.

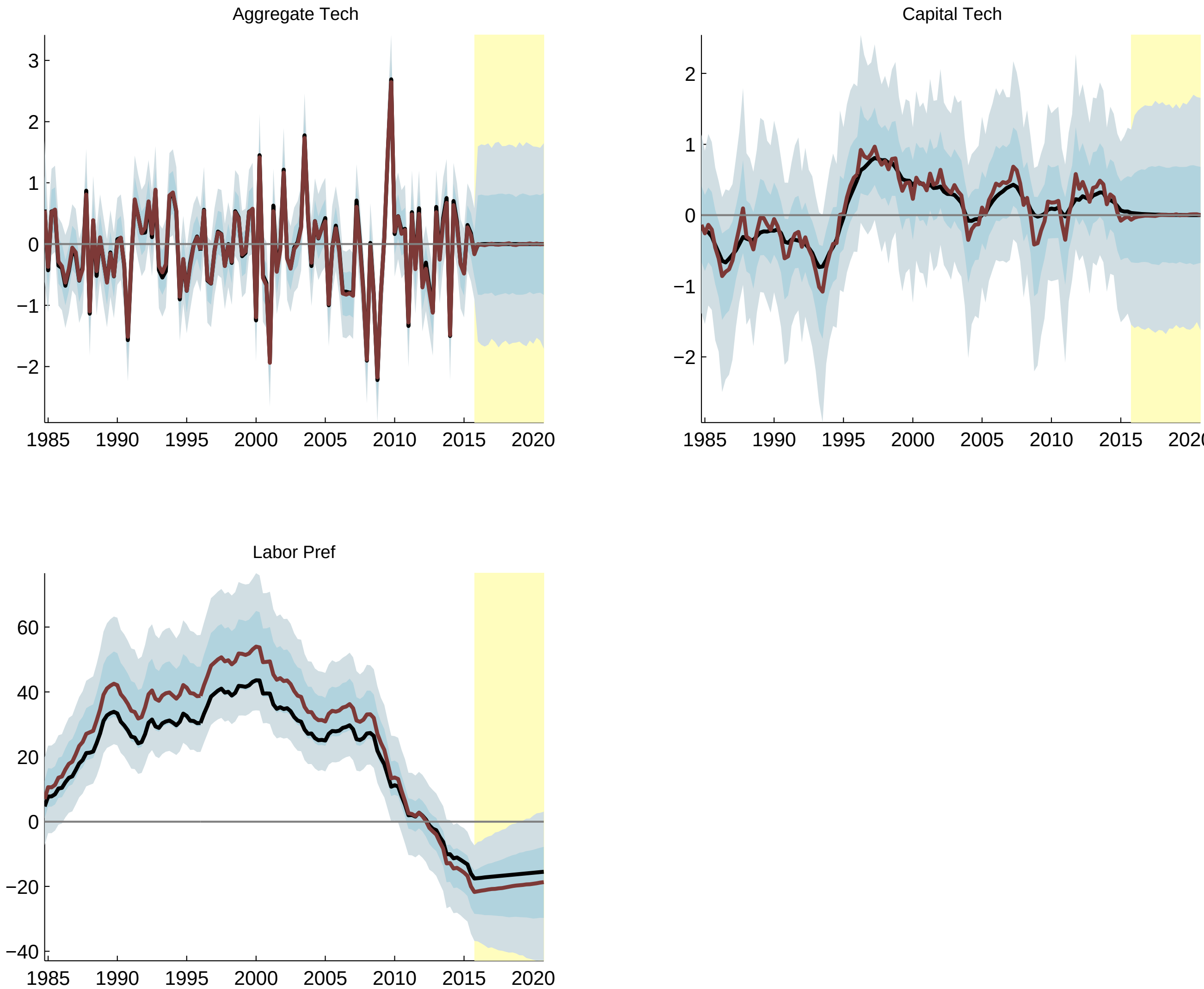
Of course, these stories from a glance at the exogenous drivers, yield applications for alternative versions of the EDO model and future model enhancements. For example, the exogenous risk premiums can easily be made to have an endogenous component, following the approach of Bernanke, Gertler, and Gilchrist (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.

Figure 4: Model Estimates of Risk Premiums



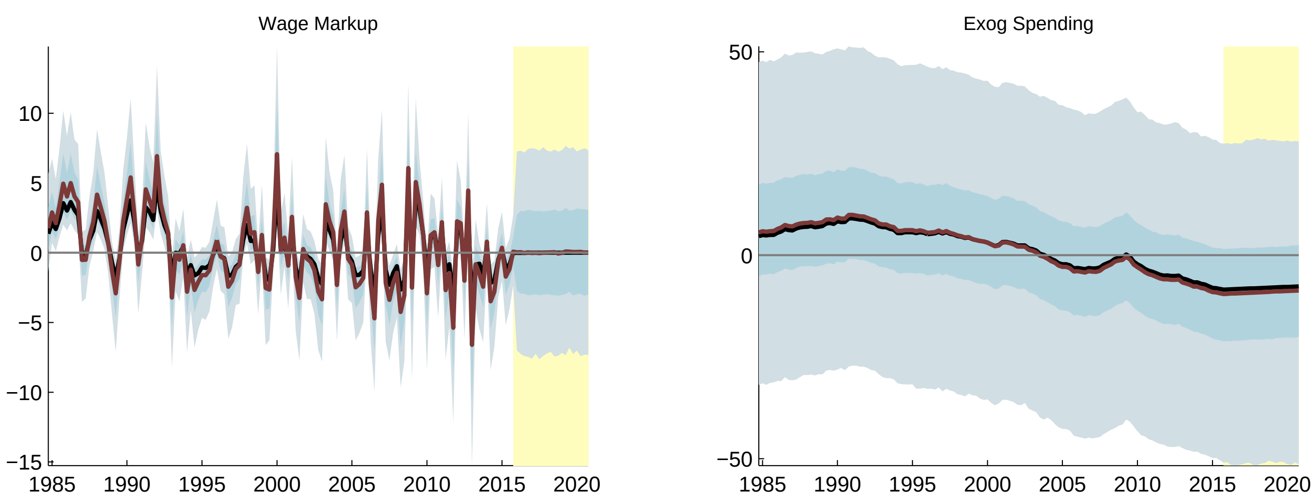
Black line: modal parameters. Red line: posterior median. Dark blue intervals: 68 percent credible set. Light blue intervals: 95 percent credible set.

Figure 5: Model Estimates of Key Supply-side Variables



Black line: modal parameters. Red line: posterior median. Dark blue intervals: 68 percent credible set. Light blue intervals: 95 percent credible set.

Figure 6: Model Estimates of Selected Other Exogenous Drivers



Black line: modal parameters. Red line: posterior median. Dark blue intervals: 68 percent credible set. Light blue intervals: 95 percent credible set.

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FRBNY DSGE Model: Research Directors Draft

December 4, 2015

Summary of the Forecasts

The FRBNY model forecasts are obtained using data released through 2015Q3, augmented for 2015Q4 with the FRBNY staff forecasts (as of November 25) for real GDP growth and core PCE inflation, and with values of the federal funds rate and the spread between Baa corporate bonds and 10-year Treasury yields based on 2015Q4 averages up to November 25. We no longer constrain the expected federal funds rate to be equal to market expectations, and instead allow the path of the federal funds rate to be determined by our policy reaction function. The projections in this memo are obtained with a version of the FRBNY DSGE model which uses two measures of output, GDP and GDI (Gross Domestic Income), broadly following the work of Aruoba et al. (2013).

The model projects real GDP to grow 2.2 percent in 2015 (Q4/Q4), up slighty from 2.0 percent in September. By contrast, for 2016, 2017 and 2018, the current growth forecasts are revised downward by about two tenth of a percent: to 1.9, 2.2 and 2.3 percent respectively. Accordingly, inflation forecasts are revised down slightly to 1.3, 1.0 and 1.1, respectively, in 2015, 2016 and 2017. For 2018, the inflation forecast remains unchanged at 1.3 percent.

The changes in the FRBNY DSGE forecasts relative to September are driven by two opposing factors. On the one hand, GDP growth was revised upward for 2015Q2, and the 2015Q3 data came out higher than the September FRBNY staff forecast for that quarter. This boosted the 2015Q4 growth forecast. On the other hand, the Baa-Treasury spread, which in the model measures the tightness of financial conditions, remained elevated in Q4 and actually increased slightly, offsetting the positive impact of the data revisions. As a result, GDP growth projections have been lowered somewhat through the forecast horizon, as financial conditions are estimated to have persistent effects on economic growth. Regarding core PCE inflation, the 2015Q3 data came in slightly below the September FRBNY staff forecast. Together with a lower projected path for economic activity, this surprise results in a slight reduction in the inflation forecast.

Overall, the forecasts remain in line with the narrative that we have been developing this year. The headwinds that slowed down the economy in the aftermath of the financial crisis are finally abating, but the recent turbulence in financial markets and the associated widening of credit spreads represent a partial set-back to this normalization process. As a result, the output gap the difference between output and natural output is moving sideways, and is projected to remain around -2.5 percent through 2018. Uncertainty about the level of the gap is however extremely large, as outlined below. The real natural rate of interest is still slightly negative and is projected to increase very slowly, reaching 0.3, 0.6 and 0.8 percent at the end of 2016, 2017 and 2018, respectively. Although the model at this stage interprets the tightening of financial conditions as temporary, relative to the September projections the natural rate of interest currently remains negative for an extra quarter, and the output gap is projected to be slightly larger over the forecast horizon. In addition, inflation is projected to move even more slowly towards the FOMC longer-term objective.

Consistent with these forecasts, the projected path for the federal funds rate is a tad shallower than forecasted in September. In the current projections the federal funds rate remains below 2 percent through the end of 2018Q1, one quarter longer than forecasted in September. This path reflects in part the endogenous response of policy to lower inflation and a more negative output gap, according to the historical reaction function estimated by the model. Despite this subdued path, the projected FFR implies a path for the ex-ante real interest rate that is close to the estimated natural rate of interest This suggests that the slow renormalization path for the federal funds rate does not imply a particularly accomodative monetary policy stance.

The projections are surrounded by notable uncertainty. The width of the 68 percent probability interval for GDP growth is 4.8 percentage points in 2016, ranging from -1.0 to 3.7 percent, and widens to 5.5 percentage points in 2018, from -0.4 to 5.0 percent. Uncertainty for the real natural rate and the output gap is also extremely large. For 2018, the 68 percent bands for the natural rate range from -.8 to 2.3 percent, while those for the output gap range from -7.4 to 0.6 percent. The 68 percent probability intervals for inflation range from 0.3 to 1.7 percent in 2016 and from 0.4 to 2.2 percent in 2018.

1 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 which is based on the New Keynesian model with financial frictions used in Del

Negro et al. (2015). The core of the model is based on the work of Smets and Wouters (2007) and Christiano et al. (2005): It builds on the neo-classical growth model by adding nominal wage and price rigidities, variable capital utilization, costs of adjusting investment, and habit formation in consumption. The model also includes credit frictions as in the *financial accelerator* model developed by Bernanke et al. (1999), where the actual implementation of the credit frictions follows closely Christiano et al. (2014); and it allows for a time-varying inflation target following Del Negro and Schorfheide (2012). In contrast to these papers, the model features both a deterministic and a stochastic trend in productivity. Finally, it accounts for forward guidance in monetary policy by including anticipated policy shocks as in Laseen and Svensson (2011). More details on the model are in the FRBNY DSGE Model Documentation, available upon request.

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 numerous quarterly data series: real GDP and GDI growth, real consumption growth, real investment growth, real wage growth, hours worked, inflation as measured by the personal consumption expenditures deflator and the GDP deflator, the federal funds rate (FFR), the 10-year nominal Treasury bond yield, 10-year survey-based inflation expectations, the Baa/10-year Treasury bond yield spread, and data on total factor productivity. In addition, from 2008Q4 to 2015Q2, we use market expectations of future federal funds rates. Model parameters are estimated from 1960Q1 to the present using Bayesian methods.

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 derive utility from leisure, supply labor services to firms, and set wages in a monopolistically competitive fashion. The labor market is subject to frictions because of nominal wage rigidities. In addition, we allow for exogenous disturbances to wage markups, labeled "wage mark-up" shocks, which capture exogenous changes in the degree of competitiveness in the labor market, or other exogenous movements in the labor supply.

Households, who discount future utility streams, also have to choose how much to consume and save. Their savings take the form of deposits to banks and purchases of government bills. Household preferences feature habit persistence, a characteristic that affects their consumption smoothing decisions. In addition, "discount factor" shocks drive an exogenous wedge between the change in the marginal utility of consumption and the riskless real return. These shocks possibly capture phenomena like deleveraging, or increased risk aversion.

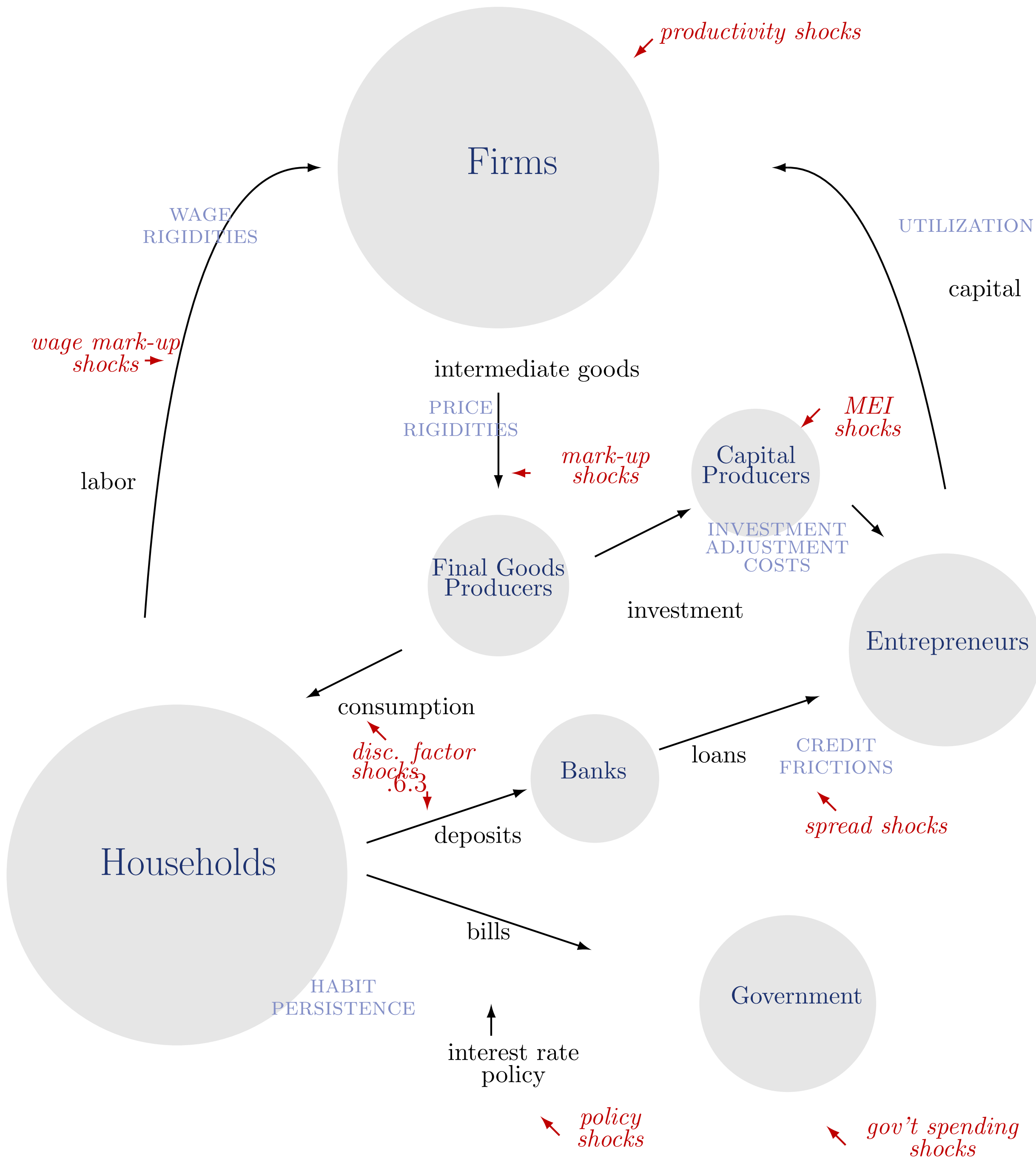
Monopolistically competitive firms produce intermediate goods, which a competitive firm aggregates into the single final good that is used for both consumption and investment. The production function of intermediate producers is subject to "total factor productivity" (TFP) shocks, which affect both the temporary and the permanent component of the level of total factor productivity. 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 with indexing, which determines inflation as a function of marginal costs, expected future inflation, past inflation, and "price mark-up" shocks. The latter 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 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 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 mark-up shocks which have also a moving-average component, disturbances to government spending which are allowed to be correlated with total factor productivity disturbances, and exogenous disturbances to the monetary policy rule, or "policy" shocks, which are assumed to be i.i.d.

Figure 1: Model Structure



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 6 to 11.

We start with the shocks most closely associated with the Great Recession and the severe financial crisis that characterized it: the discount factor shock and the spread shock. The discount factor shock reflects the sudden desire by households to cut down on their consumption and save more. This may capture the fact that households want to reduce their debt level, or their increased pessimism about future economic conditions. Figure 6 shows the impulse responses of the variables used in the estimation to a one-standard-deviation innovation in the discount factor shock. Such a shock results in a decline in consumption (fourth panel in left column), and hence in aggregate demand, which leads to a decrease in output growth (top left panel), hours worked (top right panel), and real wage growth. The implied reduction in marginal costs induces measures of inflation to fall (see inflation of GDP and PCE deflators, in second and third rows). In addition, the discount factor shock implies an increase in credit spread (fifth panel in left row) which causes investment growth to contract. Monetary policy typically attempts to mitigate the decline in activity and inflation by lowering the FFR, but is unable to fully offset the shock.

The other key shock, the spread 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 yield, and the spread's comovement with output growth, inflation, and the other observables. Figure 7 shows the impulse responses to a one-standard-deviation innovation in the spread shock. An innovation of this size increases the observed spread by roughly 25 basis points (fifth panel in left column). 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 barely higher than at the trough four 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 less than three 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, and, via the New Keynesian Phillips curve, in inflation. Finally, policymakers endogenously respond to the change in the inflation and real activity outlook by cutting the federal funds rate (right panel on the third row).

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. The impulse responses to MEI shocks, shown in Figure 8, also feature a decrease in investment, output and hours worked, as well as in real wages, although these are less persistent than in the case of spread shocks. Inflation responds little however, as marginal costs are expected revert back to steady state relatively quickly. One key difference between the responses to spread and MEI shocks which 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 is the stationary TFP shock (the model features shocks to both the level and the growth rate of productivity – we discuss here the former). As shown in Figure 9, 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.

The last shock that plays a relevant role in the current economic environment is the price mark-up shock, whose impulse response is depicted in Figure 10. 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							
	2015 (Q4/Q4)		2016 (Q4/Q4)		2017 (Q4/Q4)		2018 (Q4/Q4)	
	December	September	December	September	December	September	December	September
Core PCE	1.3	1.3	1.0	1.0	1.1	1.1	1.3	1.3
Inflation	(1.1,1.5)	(1.1,1.5)	(0.3,1.6)	(0.3,1.7)	(0.2,1.9)	(0.3,2.0)	(0.4,2.2)	(0.4,2.2)
Real GDP	2.2	1.7	2.0	2.0	2.2	2.3	2.4	2.5
Growth	(1.3,3.1)	(0.7,2.4)	(-1.0,3.8)	(-1.0,4.0)	(-0.7,4.6)	(-0.4,4.8)	(-0.4,5.0)	(-0.2,5.2)

	Conditional Forecast*							
	2015 (Q4/Q4)		2016 (Q4/Q4)		2017 (Q4/Q4)		2018 (Q4/Q4)	
	December	September	December	September	December	September	December	September
Core PCE	1.3	1.4	1.0	1.1	1.1	1.2	1.3	1.3
Inflation	(1.3,1.3)	(1.2,1.6)	(0.3,1.7)	(0.4,1.8)	(0.2,1.9)	(0.3,2.0)	(0.4,2.2)	(0.4,2.2)
Real GDP	2.2	2.0	1.9	2.1	2.2	2.3	2.3	2.5
Growth	(2.2,2.2)	(1.0,2.7)	(-1.0,3.8)	(-1.0,4.1)	(-0.8,4.5)	(-0.5,4.8)	(-0.4,5.0)	(-0.2,5.2)

*The unconditional forecasts use data up to 2015Q2, the quarter for which we have the most recent GDP release, as well as the federal funds rate and spreads data for 2015Q3. In the conditional forecasts, we further include the 2015Q3 FRBNY projections for GDP growth and core PCE inflation as additional data points. Numbers in parentheses indicate 68 percent probability intervals.

We detail the forecast of three main variables over the 2015-2018 horizon: real GDP growth, core PCE inflation and the federal funds rate. For the period running from 2008 to 2015:Q3, the effects of forward guidance, or more generally of the Fed's communication, are incorporated in the model by conditioning the models forecasts of future policy rates on financial market expectations of the path of the federal funds rate. Since 2015:Q4, we have let the model set the path of the policy rate according to the historical interest rate rule, the one that we estimated over the pre-zero-lower-bound period. The projected path of the federal funds rate is, however, very similar to that implied by financial market expectations observed at the time of the forecast. The model predicts that the federal funds rate will return slowly to its long-run level.

The table above presents Q4/Q4 forecasts for real GDP growth and inflation for 2015-2018, with 68 percent probability intervals. We include two sets of forecasts. The *unconditional* forecasts use data up to 2015Q3, the quarter for which we have the most recent GDP release, as well as the federal funds rate and spreads data for 2015Q3 (we use the average realizations for the quarter up to the forecast date). In the *conditional* forecasts, we further include the 2015Q4 FRBNY staff projections for GDP growth and core PCE inflation as additional data points (as of November 25, quarterly annualized projections for 2015Q4 are 2.1 percent for output growth and 1.2 percent for core PCE inflation). Treating the 2015Q4 staff forecasts as data allows us to incorporate information about the current quarter into the DSGE forecasts for the subsequent quarters. In addition to providing the current forecasts, the table reports the forecasts included in the DSGE memo forwarded to the FOMC in advance of its September 2015 meeting.

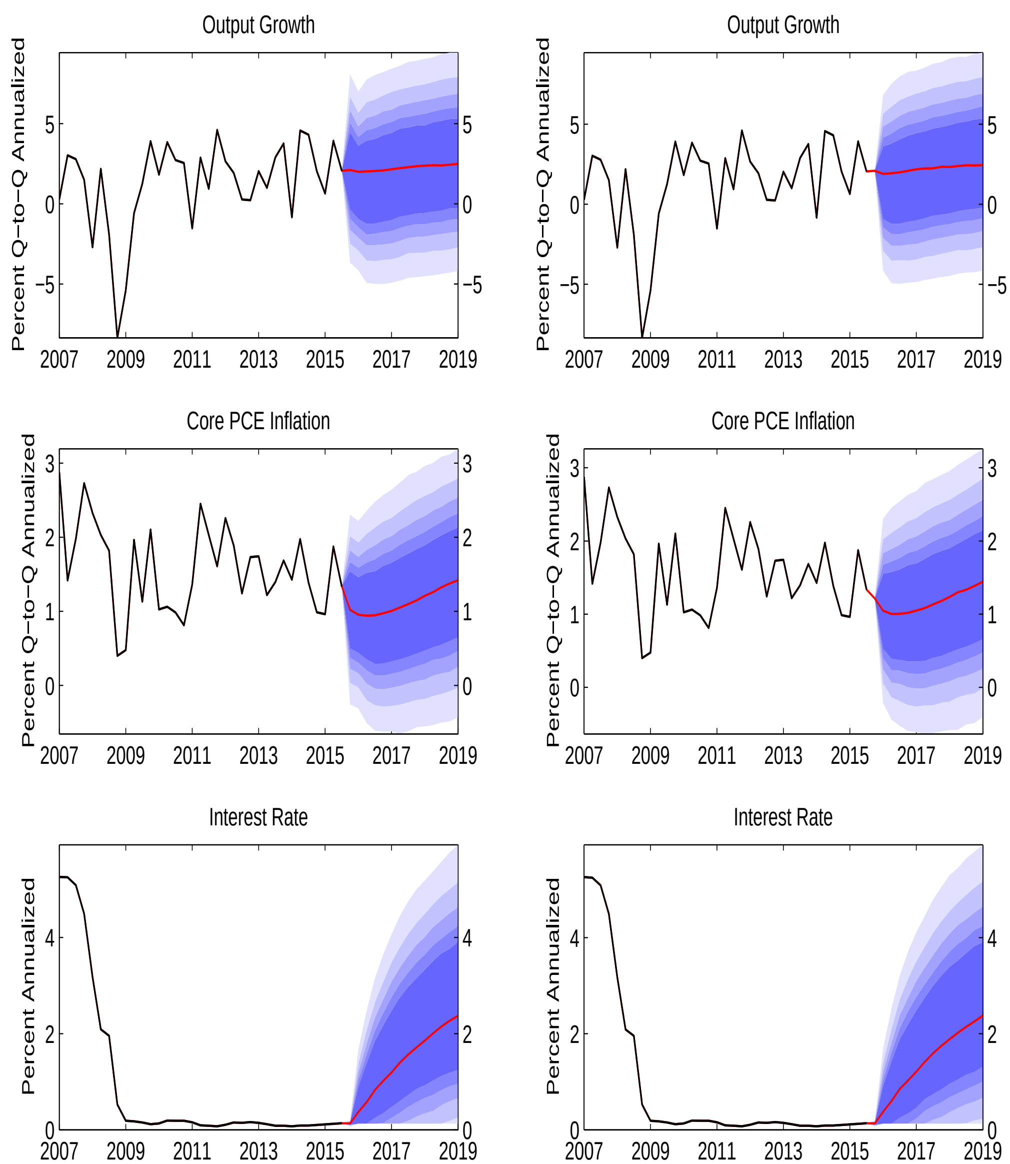
Figure 2 presents quarterly forecasts, both unconditional (left panels) and conditional (right panels). In the graphs, the black line represents data, the red line indicates the mean forecast, and the shaded areas mark the uncertainty associated with our forecast as 50, 60, 70, 80 and 90 percent probability 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.

Relative to September, the FRBNY DSGE model predicts slightly higher output in the near term, but lower growth over the rest of the forecast horizon. This change is driven by two competing forces. First, positive GDP revisions for 2015Q2 and higher-than-expected 2015Q3 data put upward pressure on the 2015(Q4/Q4) growth projection (which increased to 2.2 percent from 2.0 percent in September). However, Baa-Treasury spreads (which provide an indication of the tightness of financial conditions) remained elevated through 2015Q4. Because financial conditions have persistent effects on economic growth in the model, the December GDP growth projections (1.9, 2.2, and 2.3 percent for 2016, 2017, and 2018) fall below their respective September values (2.1, 2.3, and 2.5 percent) through the forecast horizon. 2015Q3 data for core PCE inflation came in slightly below the the September FRBNY staff forecast. Together with a lower projected path for economic activity, this surprise results in a slight reduction in the inflation forecast. The model now projects Q4/Q4 inflation of 1.3, 1.0, and 1.1 percent for 2015, 2016, and 2017, compared with 1.4, 1.1, and 1.2 percent, respectively, in September. The 2018(Q4/Q4) forecast remains unchanged at 1.3 percent.

Uncertainty around the forecast, as measured by the 68 percent probability bands, remains high for output and inflation. For GDP growth, the 68 percent probability interval spans 4.8 percentage points (from -1.0 to 3.7 percent) in 2016, and widens to 5.4 percentage points (from -0.4 to 4.0 percent) in 2018. In September, the ranges were 5.1 and 5.4 percentage points, respectively. For inflation, the 68 percent probability intervals range from 0.3 to 1.7 percent in 2016 and from 0.4 to 2.2 percent in 2018. The widths of the inflation bands remain unchanged from the September forecast. Uncertainty is also significant for the real natural rate and the output gap. For 2018, the 68 percent bands for the natural rate range from -0.8 to 2.3 percent, while those for the output gap range from -7.4 to 0.6 percent. The 68 percent probability intervals for inflation range from 0.3 to 1.7 percent in 2016 and from 0.4 to 2.2 percent in 2018.

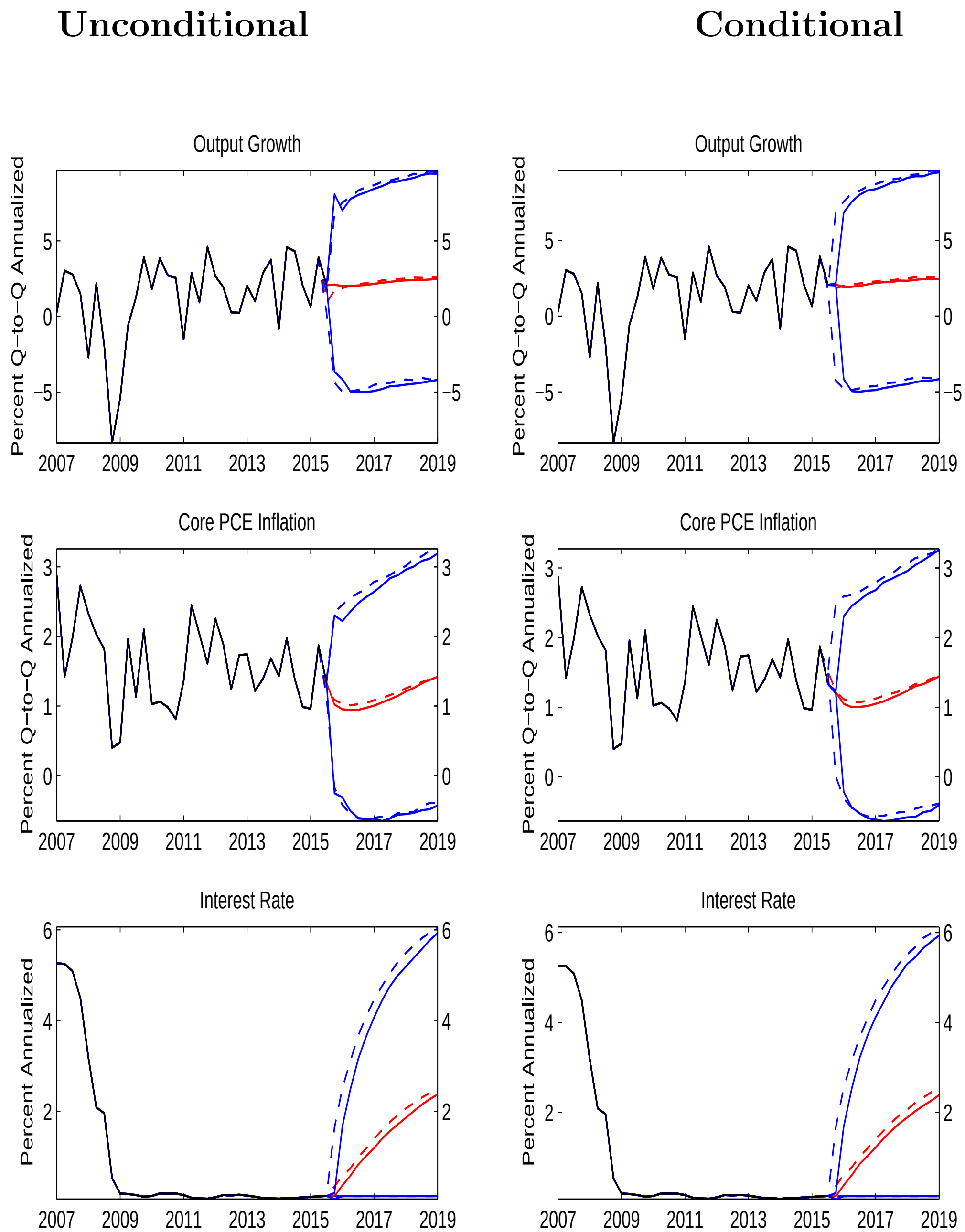
Figure 2: Forecasts

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.

Interpreting the Forecasts

We use the shock decomposition shown in Figure 4 to interpret the forecasts. This figure quantifies the relevance of the most important shocks 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. We should note that the impacts of some shocks have been aggregated. For example, the "financial" shock (purple) captures both shocks to the spread as well as shocks to the discount factor.

The dynamics behind the FRBNY DSGE forecast can be described as follows. The headwinds from the financial crisis, which are captured in the model by the contribution of the financial (purple) and MEI (azure) shocks, are finally waning, implying that both shocks have an overall positive contribution to output growth. The impact of financial shocks on the level of output is still negative throughout the forecast horizon, however, as can be inferred from their negative contribution to inflation. In fact, Figure 4 shows that financial shocks are mostly responsible for the slow return of inflation to the 2 percent target, and for the interest rate being below its steady state value.

Figure 5 shows the output gap – the difference between output and its "natural" level (the counterfactual level of output in absence of nominal rigidities, mark-up shocks, and financial frictions) – and the corresponding natural rate of interest through history. The natural rate of interest has recently risen, consistent with the waning of headwinds from the financial crisis. The output gap chart, however, suggests that there is still slack – that is, underutilized capacity – in the economy. The slack also reflects low marginal costs of production for firmsa key driver of the inflation projections. The models estimate of firms marginal costs suggests that these have not recovered much over the last few years owing to the weakness in real wage growth. The output gap thus closes only gradually, which explains the slow return of inflation to target.

Within this broad picture, the difference between this forecast and the one presented in

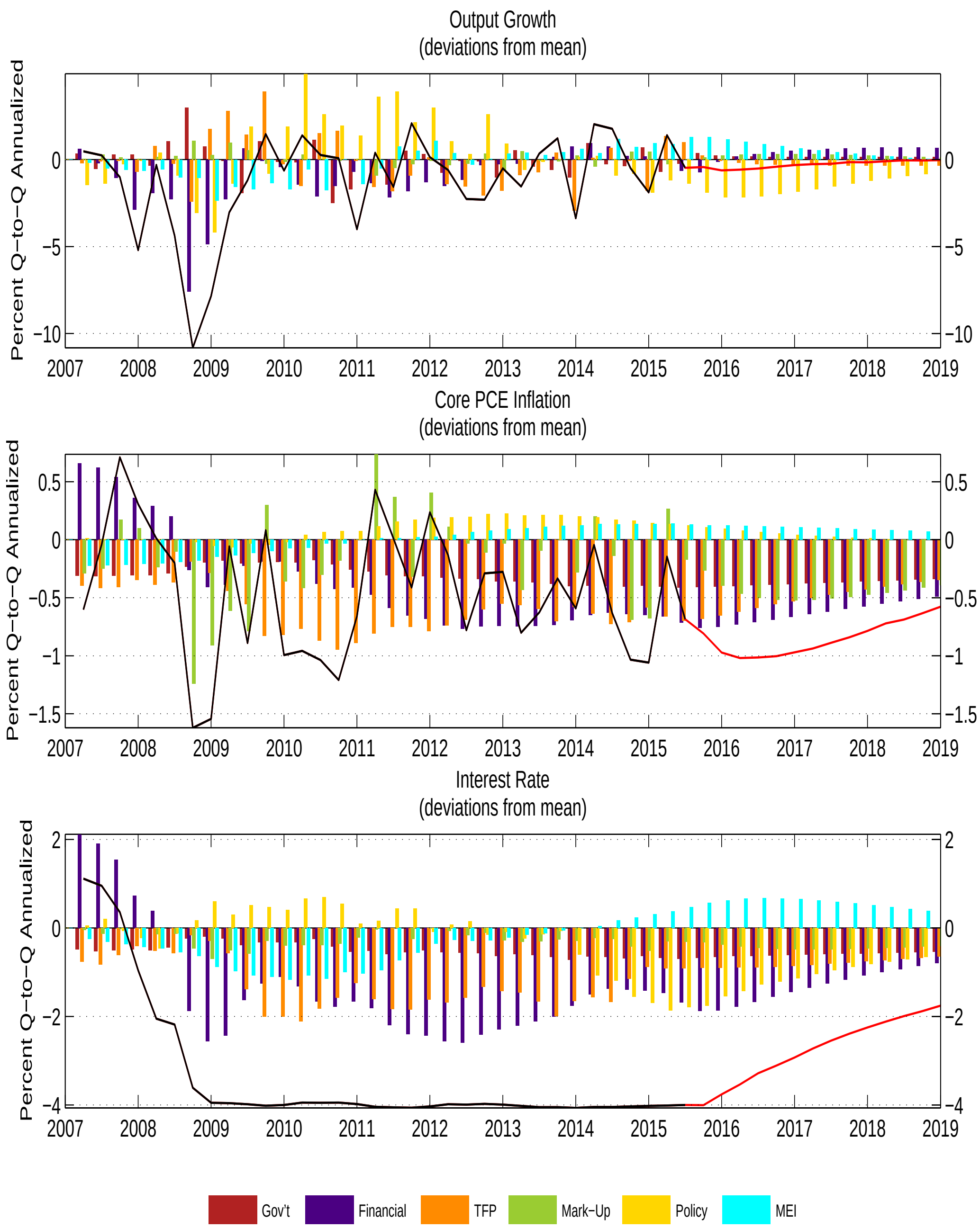
September reflects two opposing factors. On the one hand, GDP growth was revised upward for 2015Q2 and was stronger than expected for 2015Q3. This change boosted the near term forecasts for output. On the other hand, financial conditions remained tight in the current quarter, offsetting the positive impact of the data revisions: as a consequence, the medium term projections are slightly lower relative to September.

Total factor productivity shocks, which contributed negatively to economic activity in late 2007 and 2008, have instead pushed GDP up significantly in 2009 and 2010. In 2015Q1, as was the case in 2014Q1, the sharp drop in real GDP growth is mainly attributable to a temporary drop in total factor productivity. Similarly, a temporary positive productivity shock appears to drive output growth in the second quarter of 2015. Over the past several years, the negative impact of the headwinds mentioned above has been partly compensated by expansionary monetary policy. In particular, forward-guidance about the future path of the federal funds rate (captured here by anticipated policy shocks) played an important role in counteracting these headwinds, lifting both output and inflation. However, the positive effect of this policy accommodation on the level of output has been negligible over the most recent quarters. Since monetary policy is neutral in the long run in this model, the impact of policy accommodation on the level of output will wane eventually, and has already begun to do so by the end of 2014, implying a negative effect on growth.

The projected path of the federal funds rate, which follows the estimated historical rule, is very slightly shallower than projected in September. The comparison between the estimated real natural rate of interest and the actual real rate of interest, shown in Figure 5, helps to assess the stance of policy. The natural rate of interest has been well below the actual real rate during and after the crisis, indicating that the zero lower bound imposed a constraint on interest-rate policy. In the current projections the federal funds rate remains below 2 percent through the end of 2018Q1, one quarter longer than forecasted in September, reflecting in part an endogenous response of policy to lower inflation and a more negative output gap. Despite this subdued path, the projected FFR implies a path for the ex-ante real interest rate that is close to the estimated natural rate of interest.

The shock decomposition for inflation also shows that mark-up shocks (green bars), which capture the effect of exogenous changes in marginal costs such as those connected with fluctuations in commodity prices, play an important role. These shocks tend to have a fairly persistent impact on inflation. Recent negative mark-up shocks, likely reflecting declines in oil prices, contribute to push inflation down relative to target by at least half of a percentage point during the current year and the next one. The rise in inflation in 2015(Q4/Q4) is partly explained by a temporary reversal of these shocks.

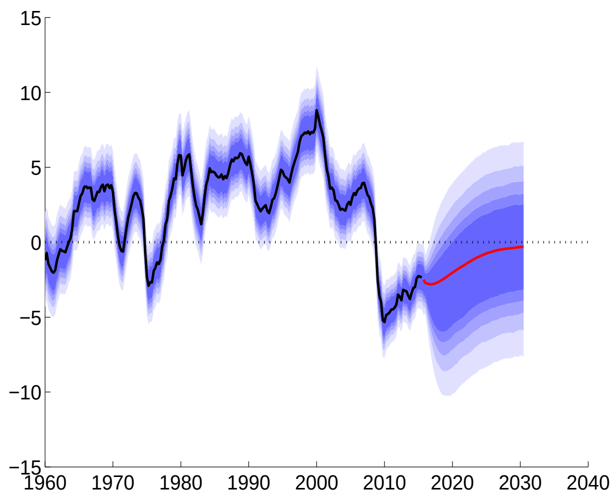
Figure 4: Shock Decomposition



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.

Figure 5: Output Gap and the Natural Interest Rate

Output Gap



Natural Rate & Ex-Ante Real Rate

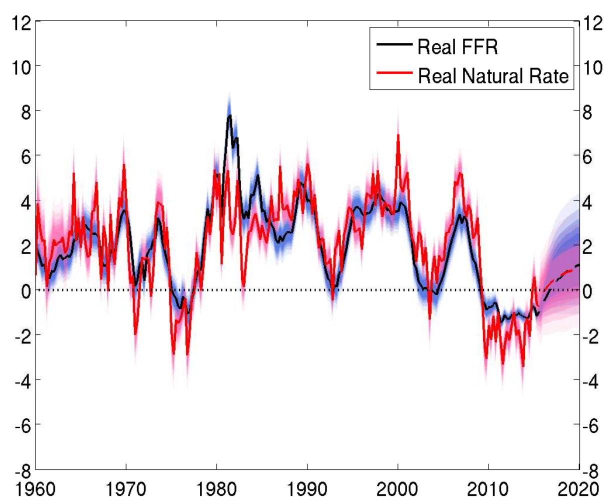


Figure 6: Responses to a Discount Factor Shock

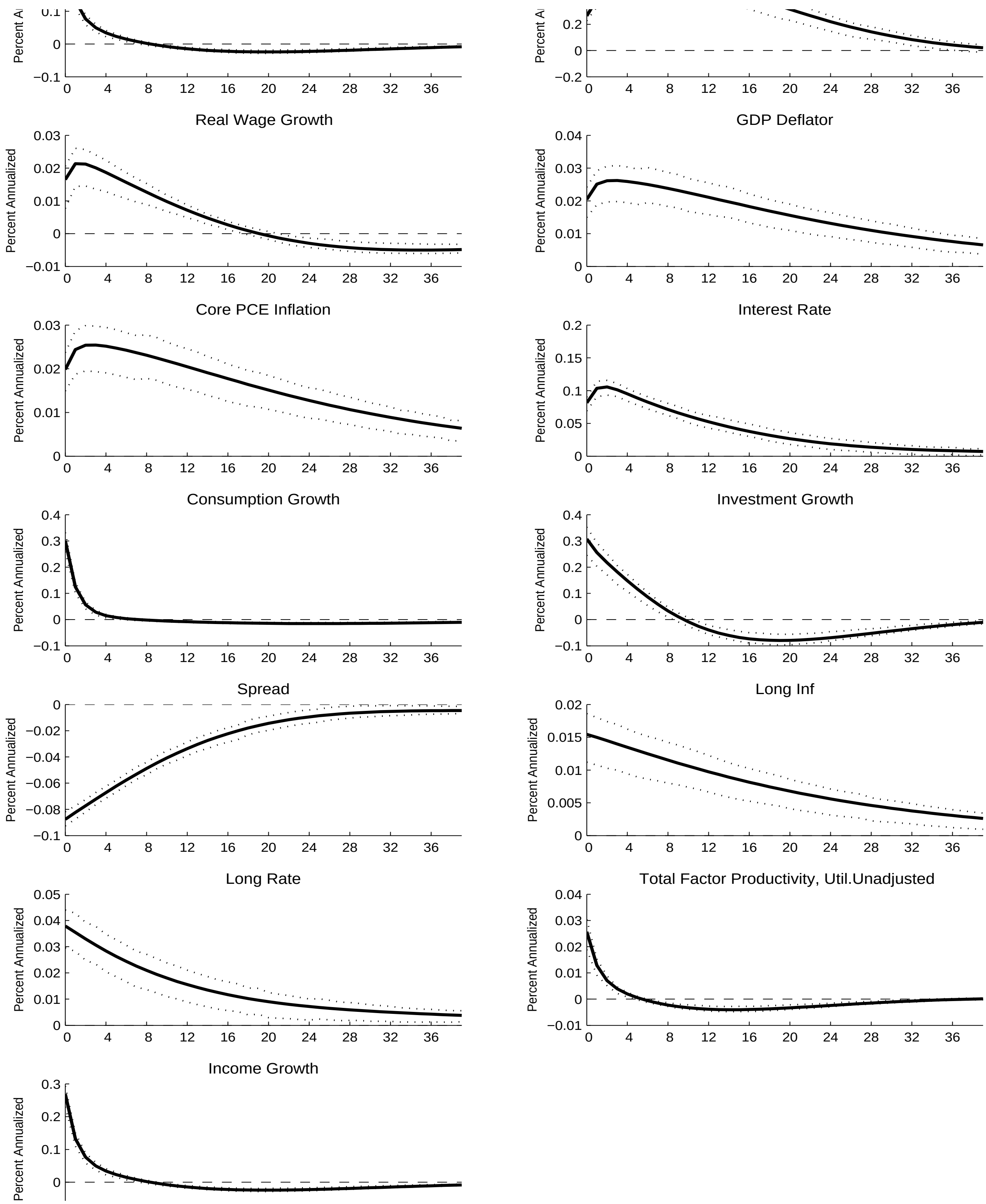


Figure 7: Responses to a Spread Shock

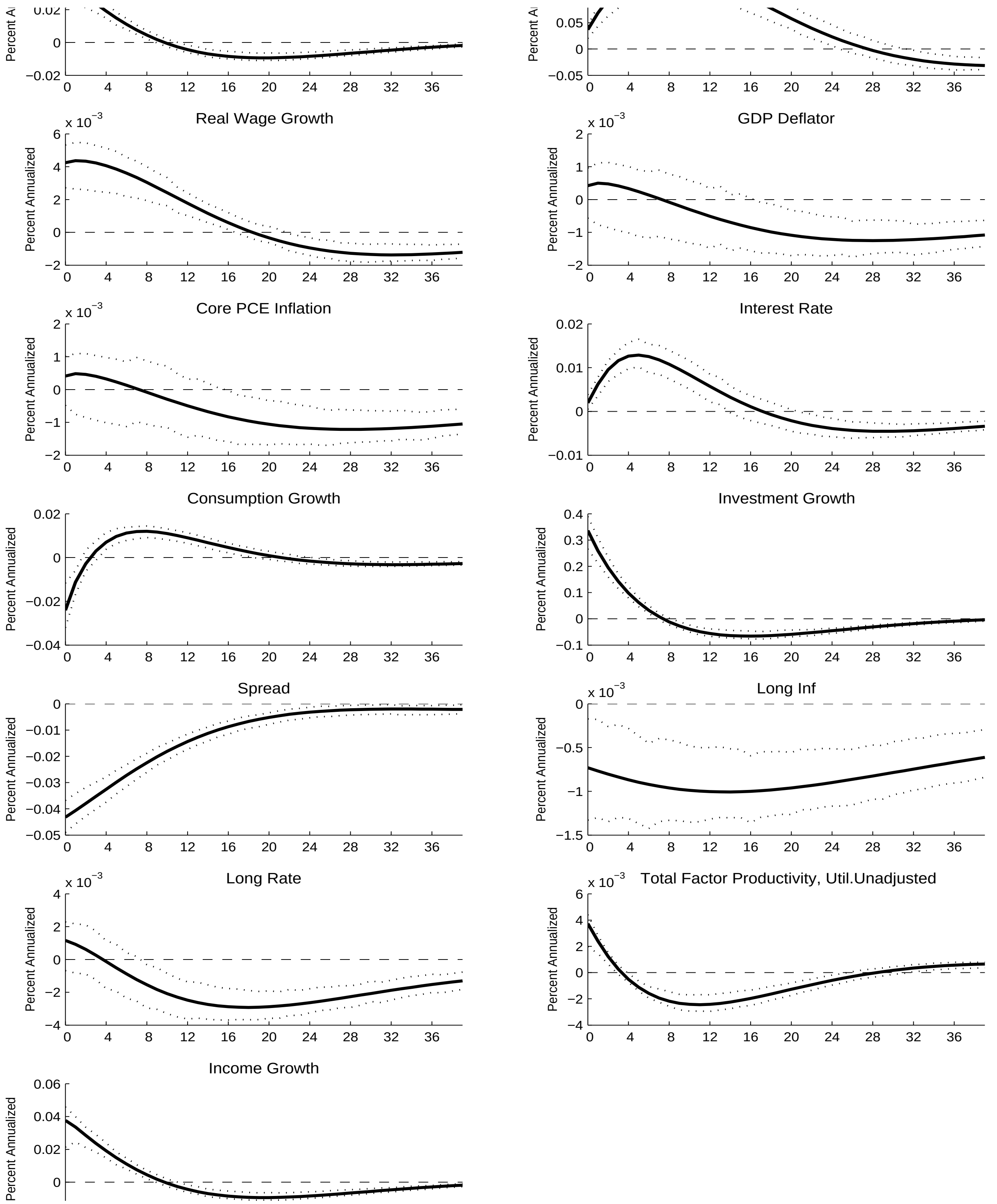


Figure 8: Responses to an MEI Shock

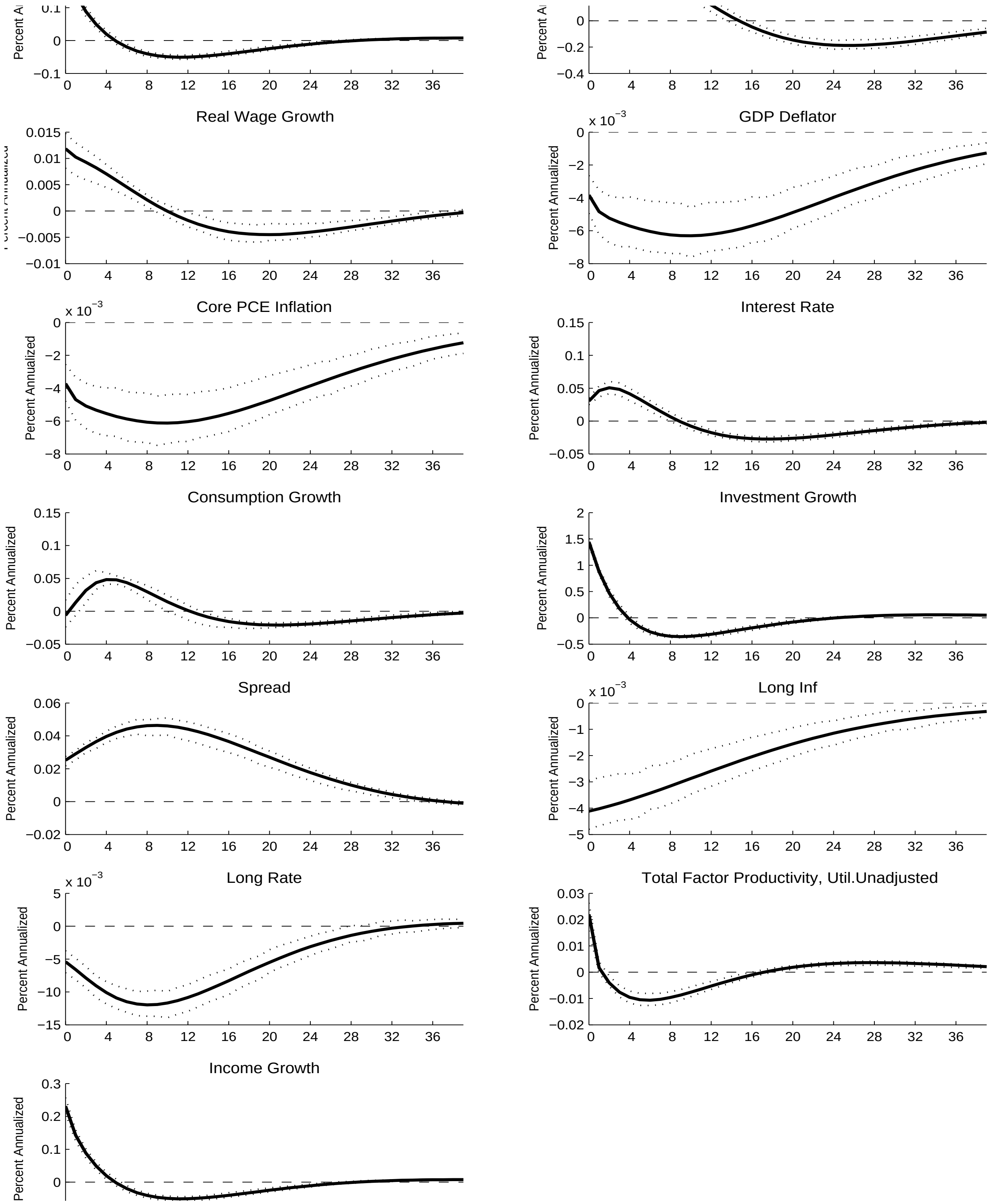


Figure 9: Responses to a TFP Shock

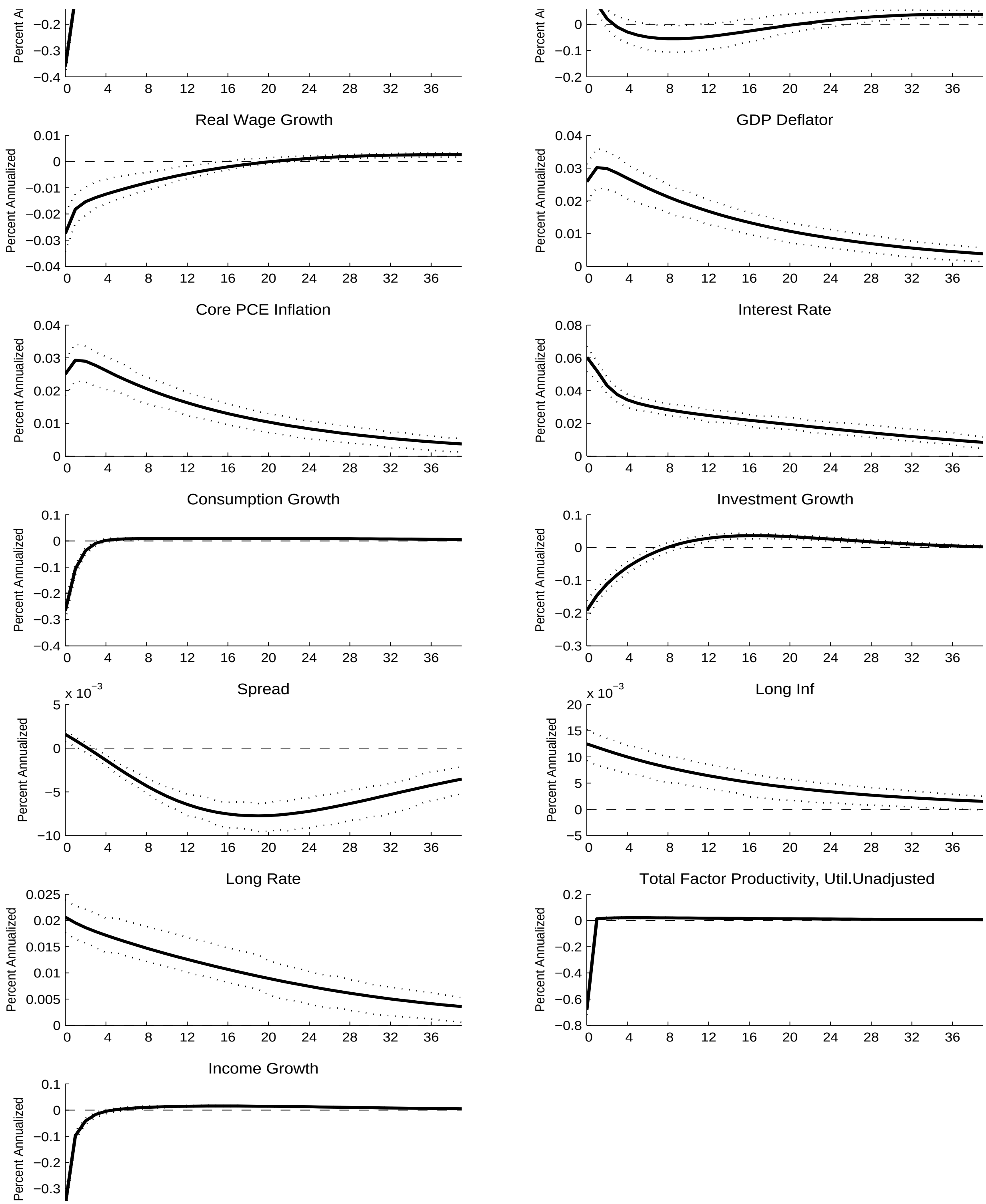


Figure 10: Responses to a Price Mark-up Shock

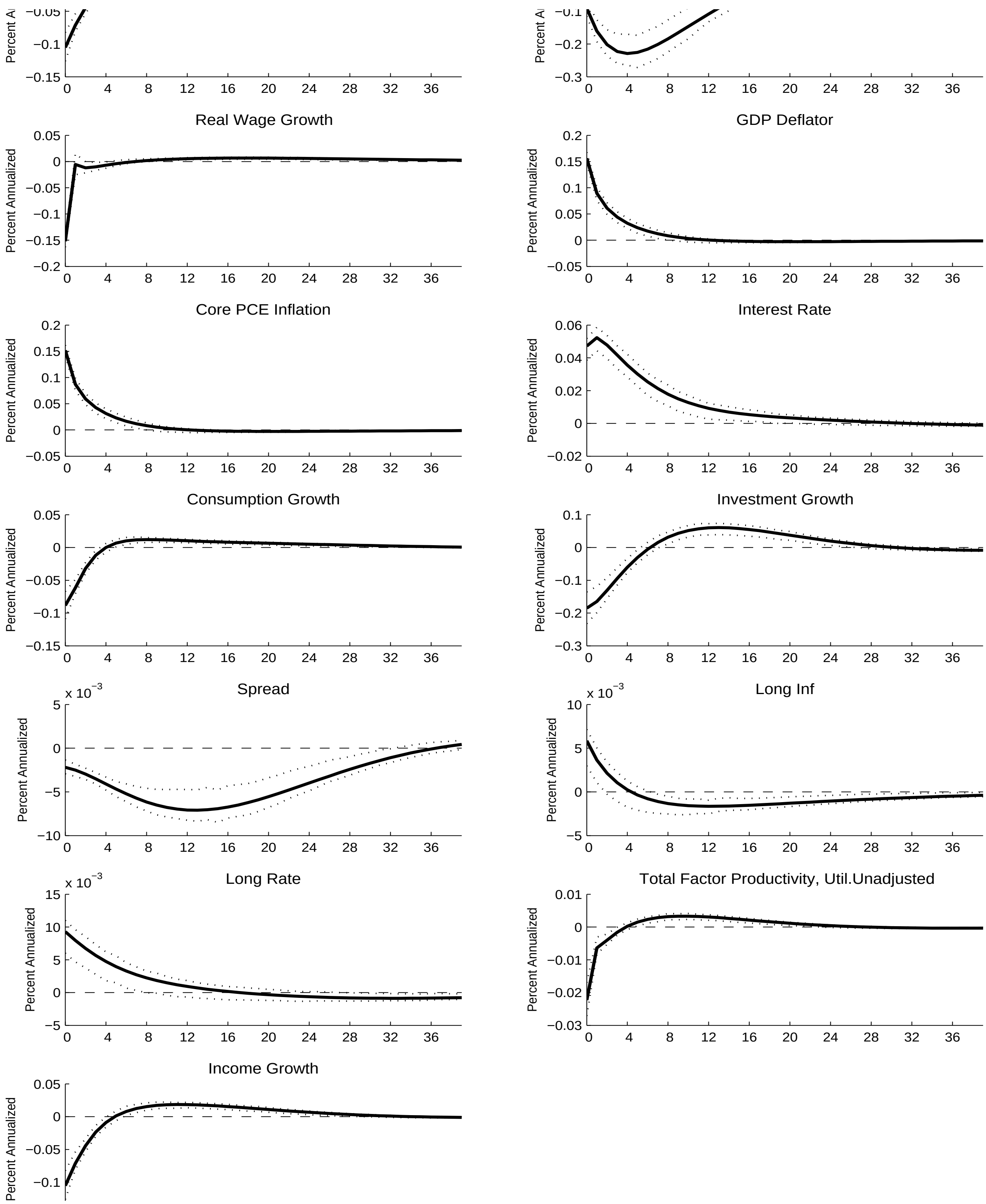


Figure 11: Responses to a Monetary Policy Shock

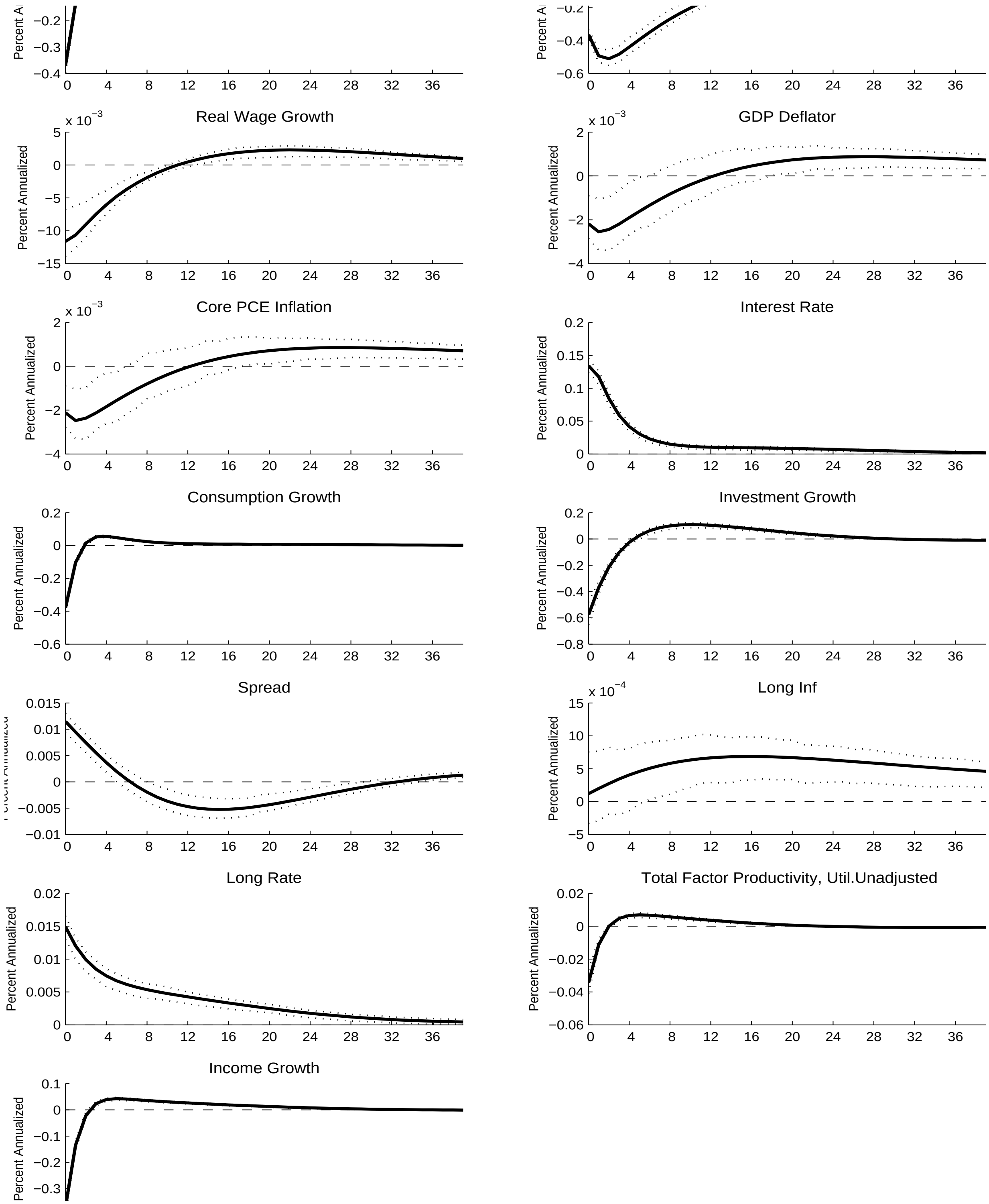


Figure 12: Shock Histories

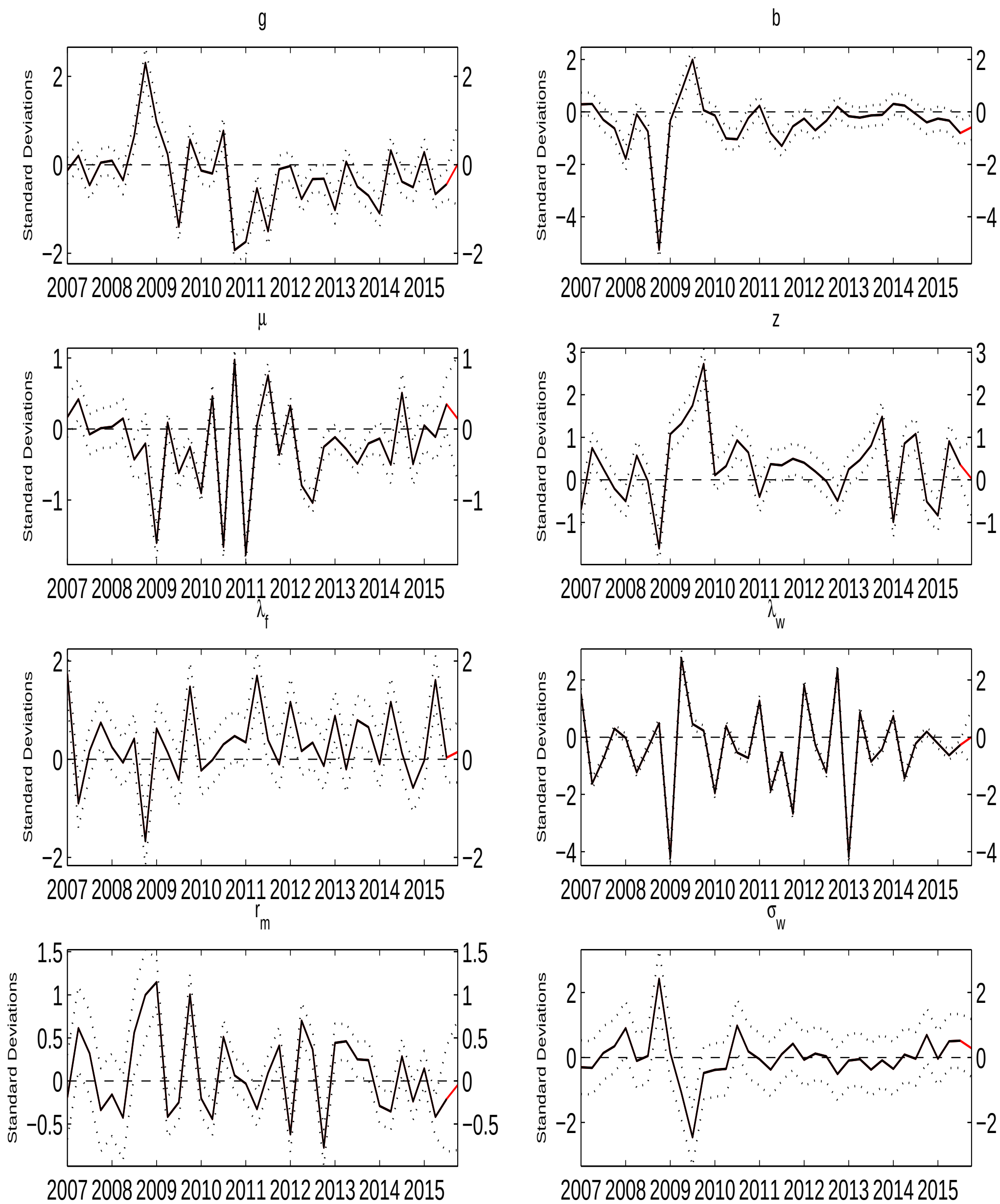
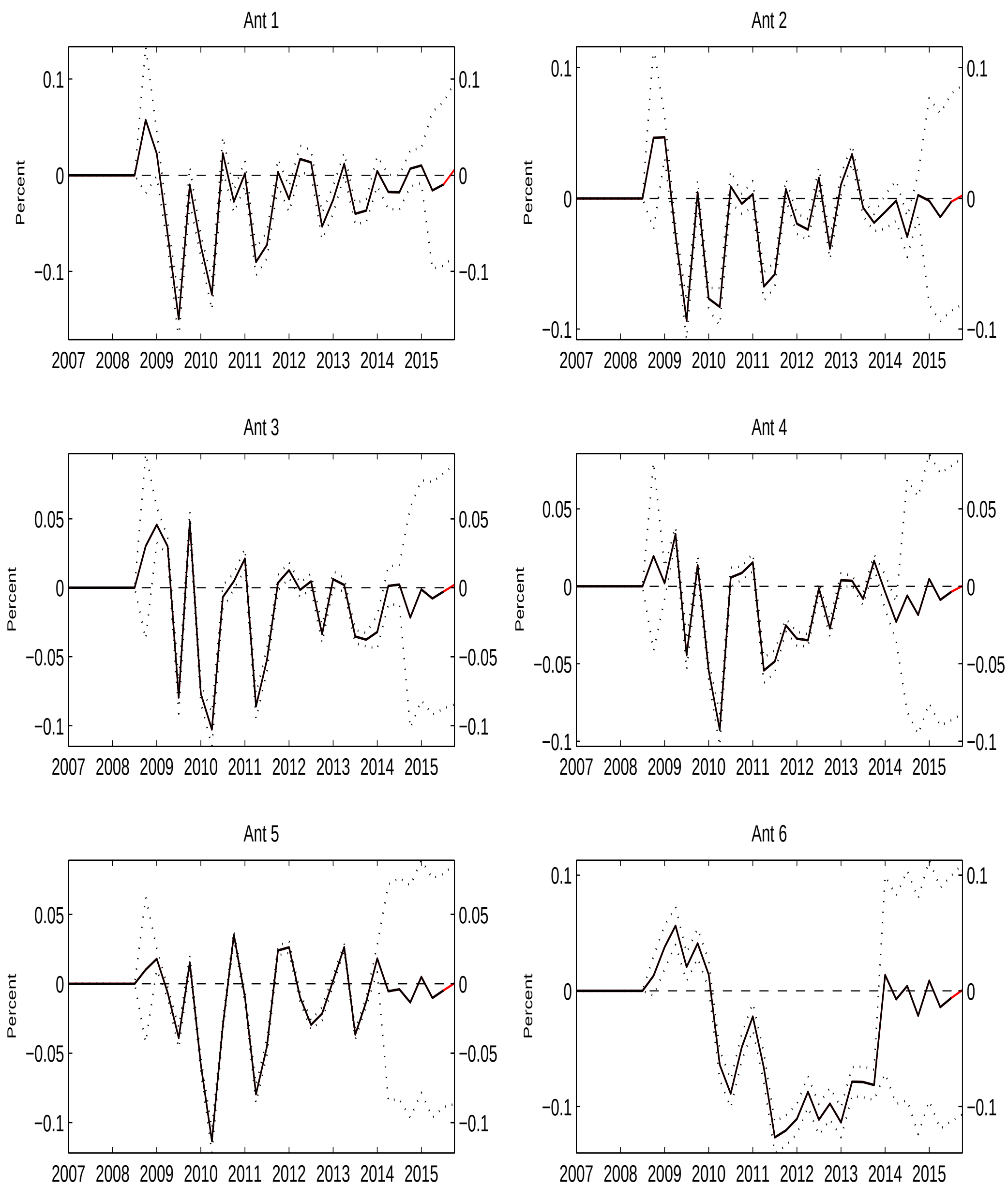


Figure 13: Anticipated Shock Histories



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Detailed Philadelphia (PRISM) Forecast Overview

December 2015

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 3.5 percent in early 2018. Core PCE inflation rises quickly to 2.2 percent, but remains contained through the forecast horizon. For this forecast round we allow the interest rate to be determined by the estimated policy rule over the full forecast horizon. The funds rate rises to 2.5 percent in 2016Q4 and reaches 4.2 percent at the end of 2018. The current gap between output and its trend level remains substantial in the estimated model and, absent any shocks, the model predicts a rapid recovery to the trend level. The relatively slow pace of growth and low inflation that have characterized U.S. economic performance over the past few years 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 2015Q3 supplemented by a 2015Q4 nowcast based on the latest Macroeconomic Advisers forecast. For example, the model takes 2015Q4 output growth of 2.2 percent as given and the projection begins with 2016Q1. PRISM anticipates that output growth accelerates to 2.9 percent in 2016Q1, and then edges up gradually to about 3.5 percent in 2018Q1. Overall, the growth forecast for this round is a bit weaker compared with the September projection due to the modest growth in the economy in second half of 2015. While output growth is fairly robust going forward, core PCE inflation stays contained and remains at 2.2 percent or below over the next three years. 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 determined solely by model dynamics for this forecast round and the funds rate rises to 2.5 percent in 2016Q4, 3.7 percent in 2017Q4, and 4.2 percent in 2018Q4. This path is slightly stronger compared to the September 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). Over the course of 2015, negative shocks to TFP, government spending, and monetary policy have been the primary factor holding back real output growth. As these shocks unwind, output growth rises with additional contributions from the unwinding of investment and labor supply shocks. 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 series of large negative discount factor shocks since 2008. All else equal, these shocks push down consumption and push up investment, with the effect being very persistent. Consequently, the de-trended level of consumption (nondurables + services) still remains somewhat below the model's estimated steady state at this point. As these shocks unwind over the projection period, consumption growth gradually accelerates from about 2.1 percent in mid-2016 to 2.9 percent in the second half of 2018. The model is now forecasting a relatively weak path for investment growth (gross private domestic + durable goods consumption) as the gradual unwinding of a history of negative MEI shocks since the start of the recession (see Figures 2e and 3) are offset by the lingering effects of financial shocks: the unwinding of the discount factor shocks leads to a downward pull on investment growth over the next three years. Investment growth rises from about 1.4 percent at the beginning of 2016 to 3.4 percent at the end of the forecast horizon.

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 at 2.2 percent or below through 2018.

The federal funds rate is projected to rise fairly quickly over the forecast horizon. The model attributes the low level of the funds rate to a combination of monetary policy, discount factor and MEI shock dynamics. Looking ahead, the positive contribution from labor supply shocks is more than offset by discount factor shock dynamics, but as these shocks wane the funds rate returns to its steady state level by the end of 2018.

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Figure 1a

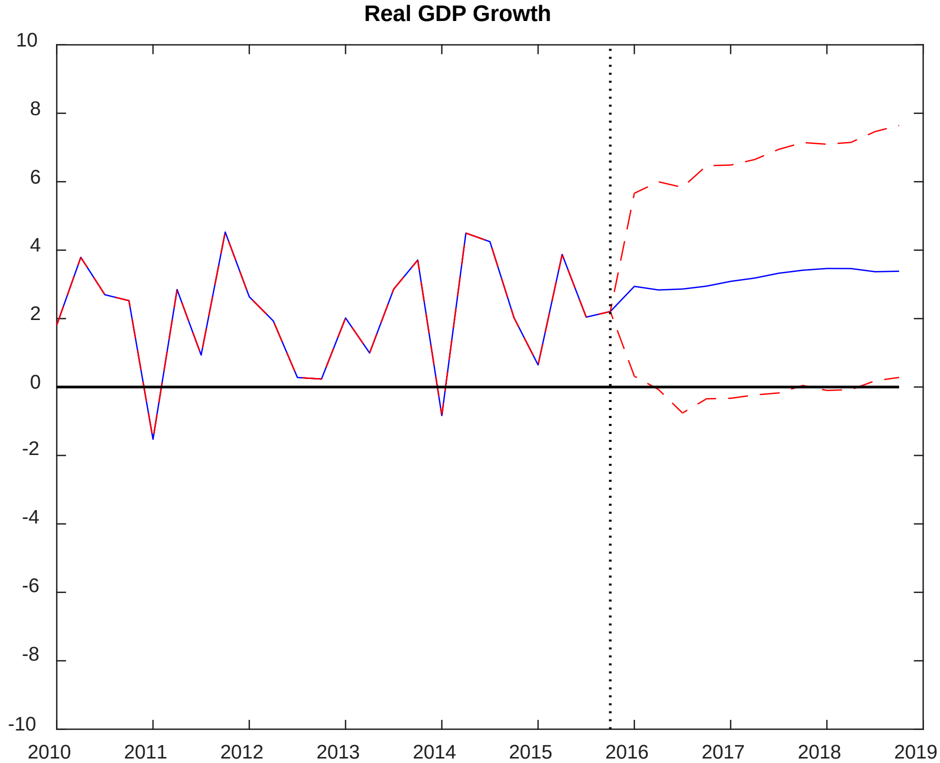

Real GDP Growth
10
8
6
4
2
0
-2
-4
-6
-8
-10
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 1b

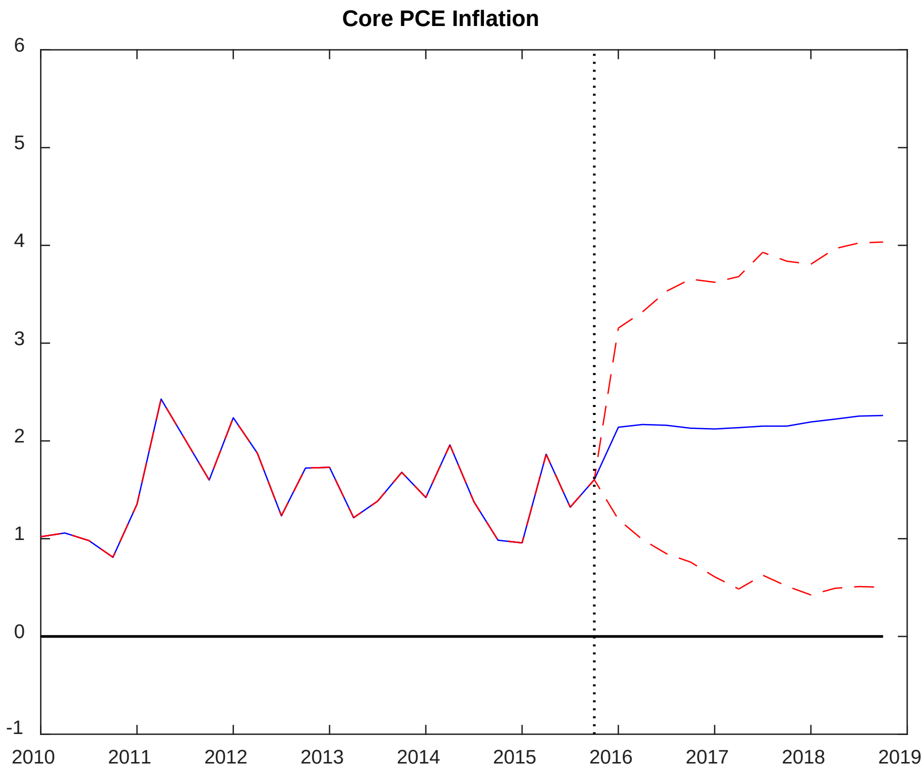

Core PCE Inflation
6
5
4
3
2
1
0
-1
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

Figure 1c

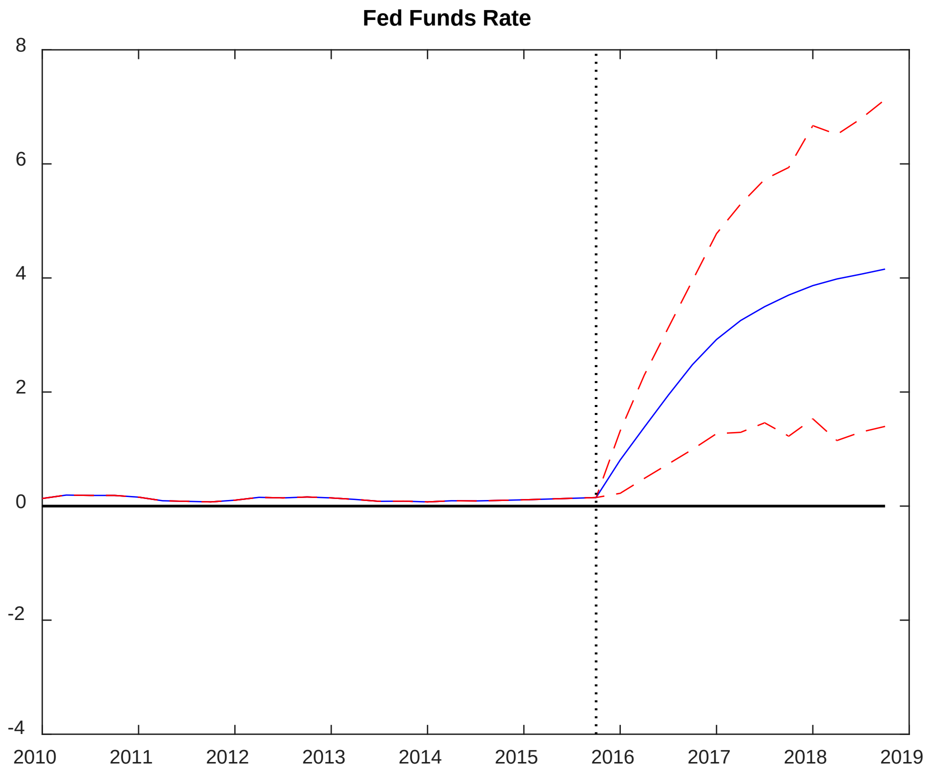
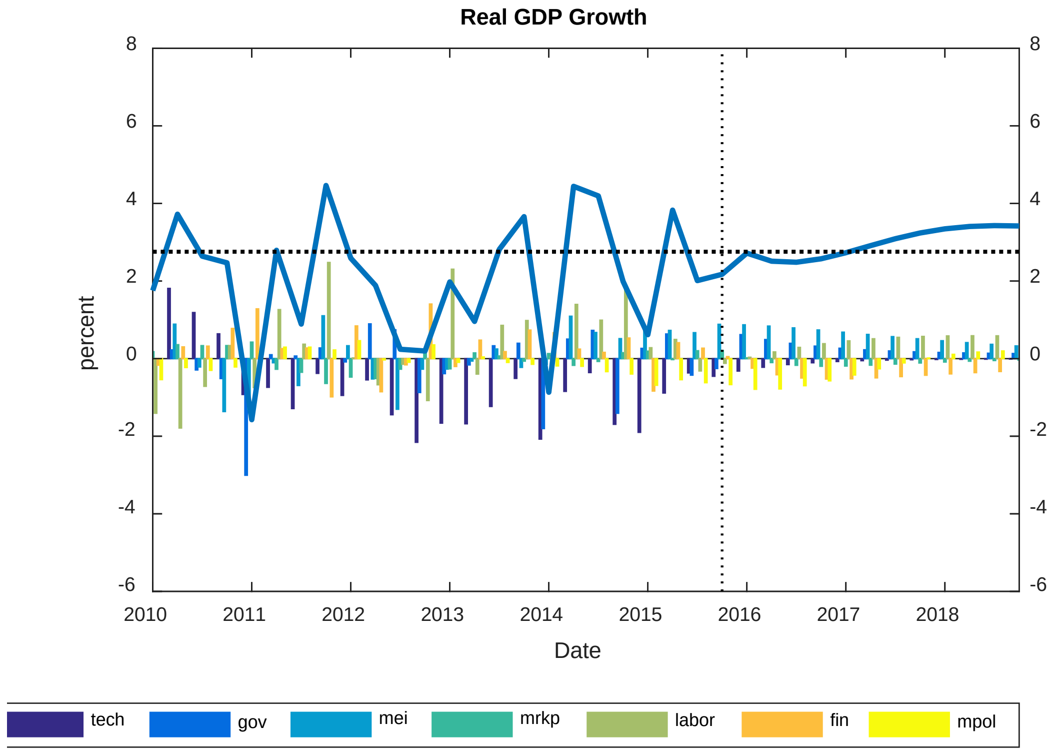

Fed Funds Rate
8
6
4
2
0
-2
-4
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

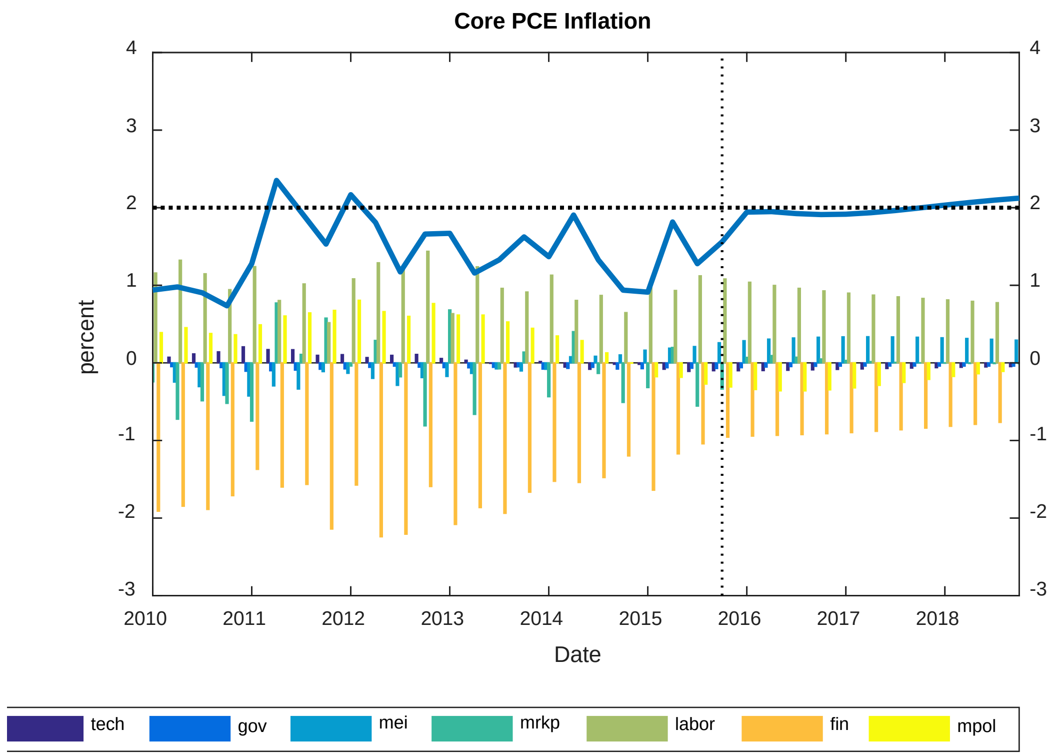
Figure 2a
Conditional Forecast



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

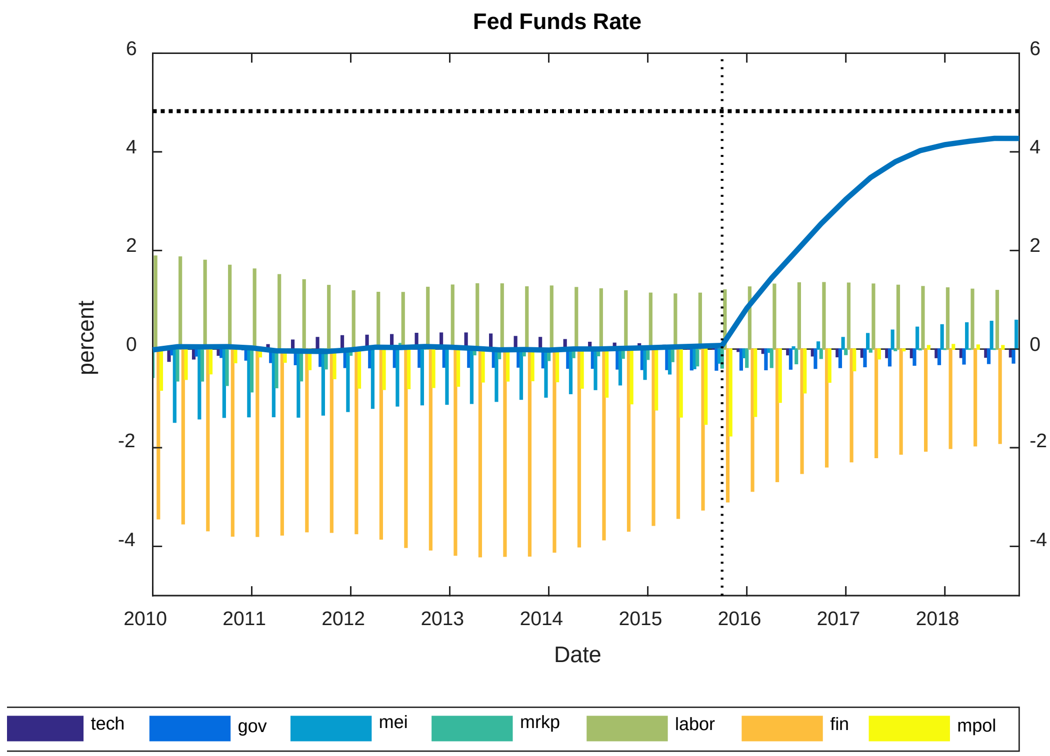
Figure 2b
Conditional Forecast



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

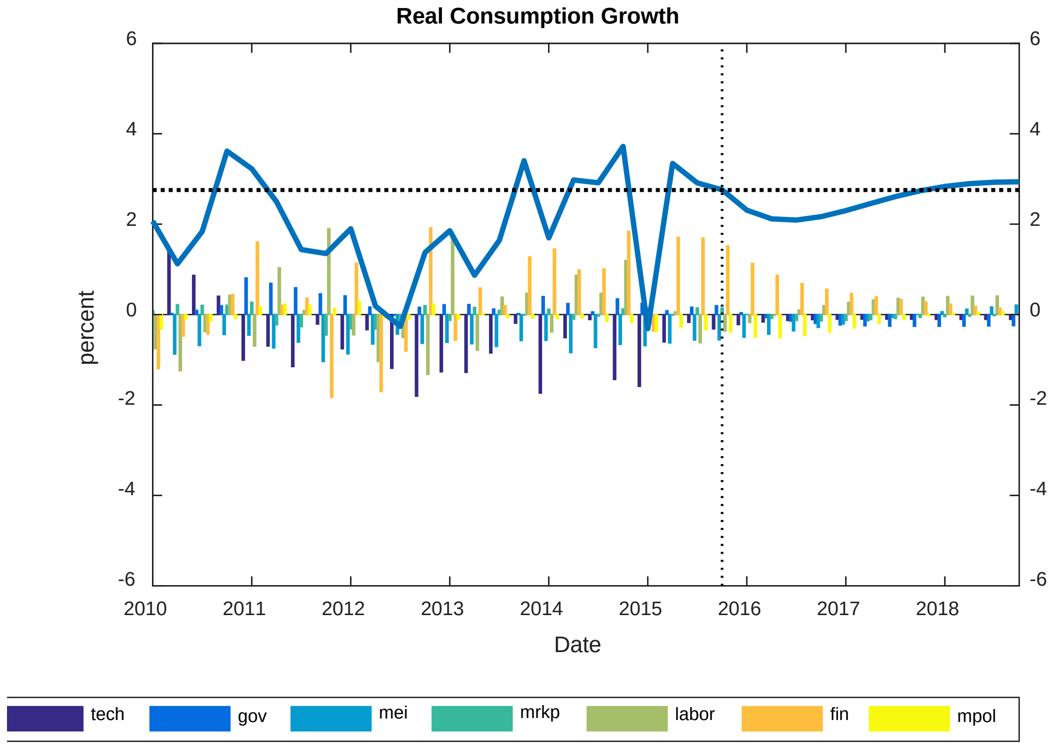
Figure 2c
Conditional Forecast



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

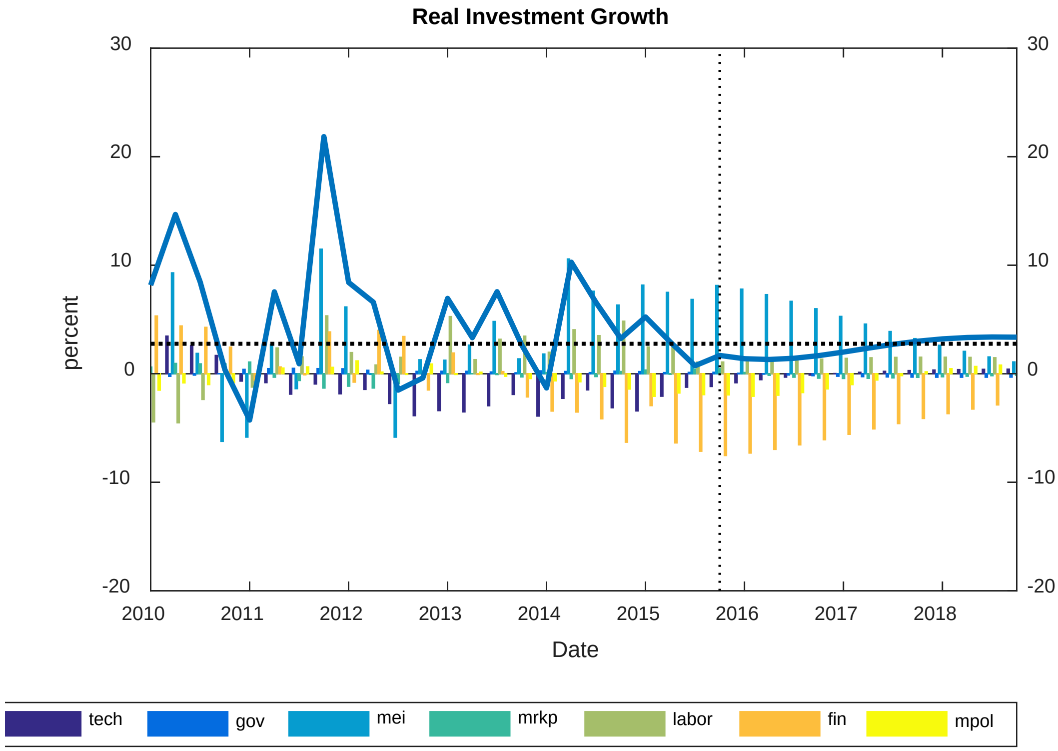
Figure 2d
Conditional Forecast



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

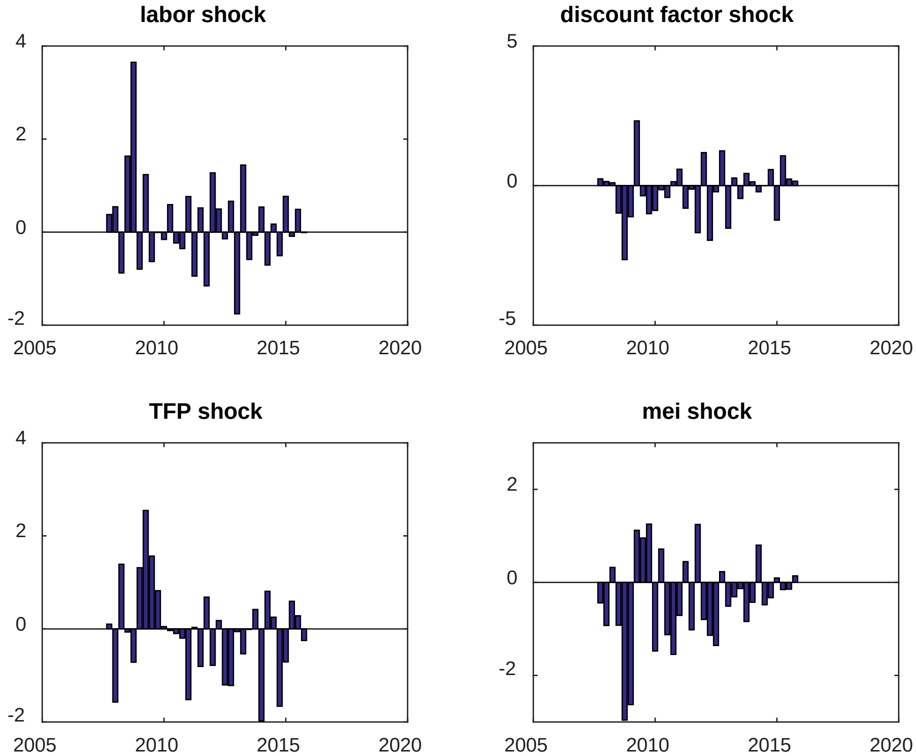
Figure 2e
Conditional Forecast



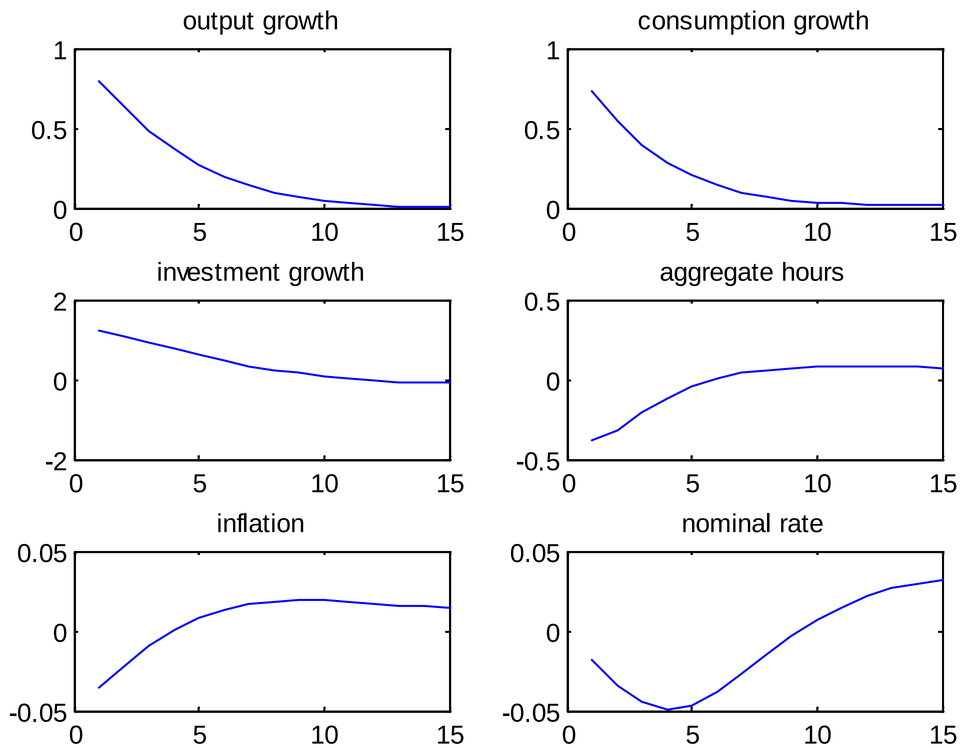
shocks:

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

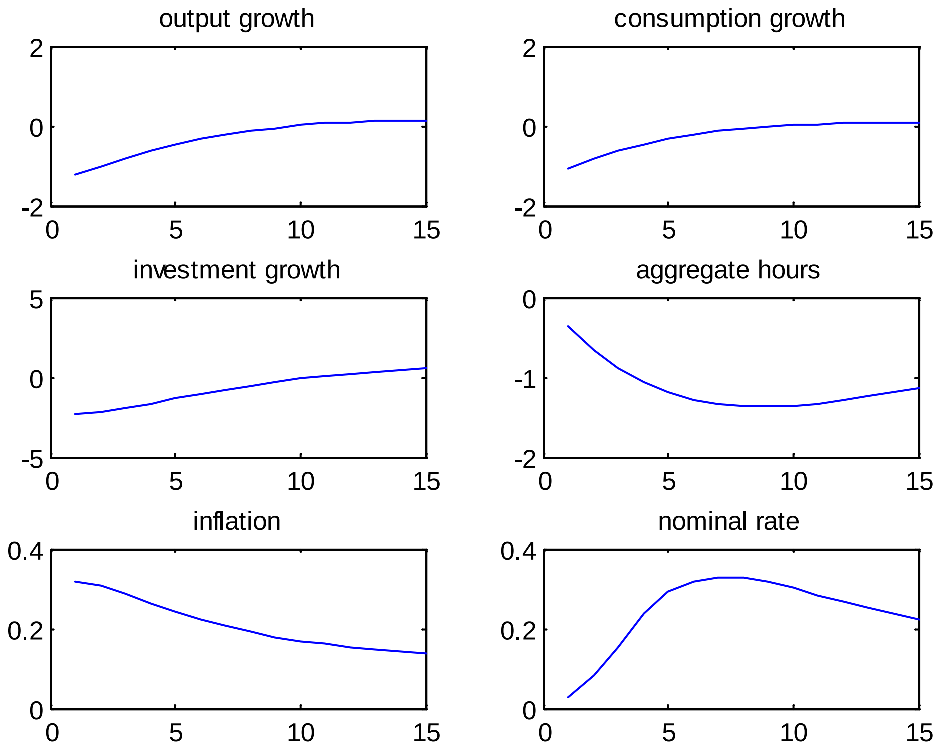
Figure 3
Smoothed Shock Estimates for Conditional Forecast Model
(normalized by standard deviation)



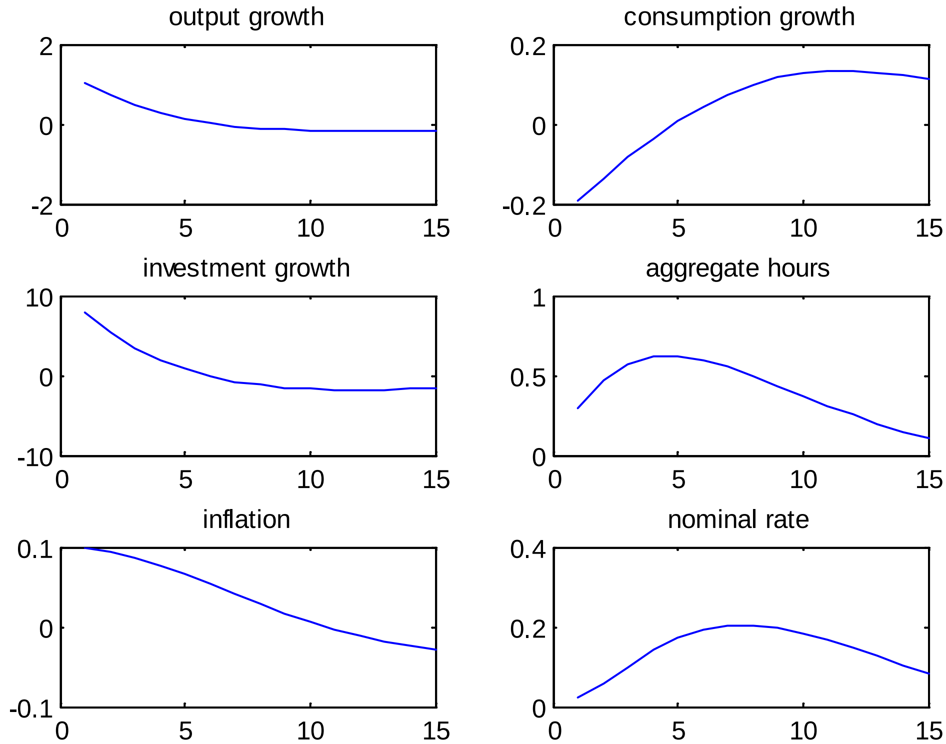
Impulse Responses to TFP shock



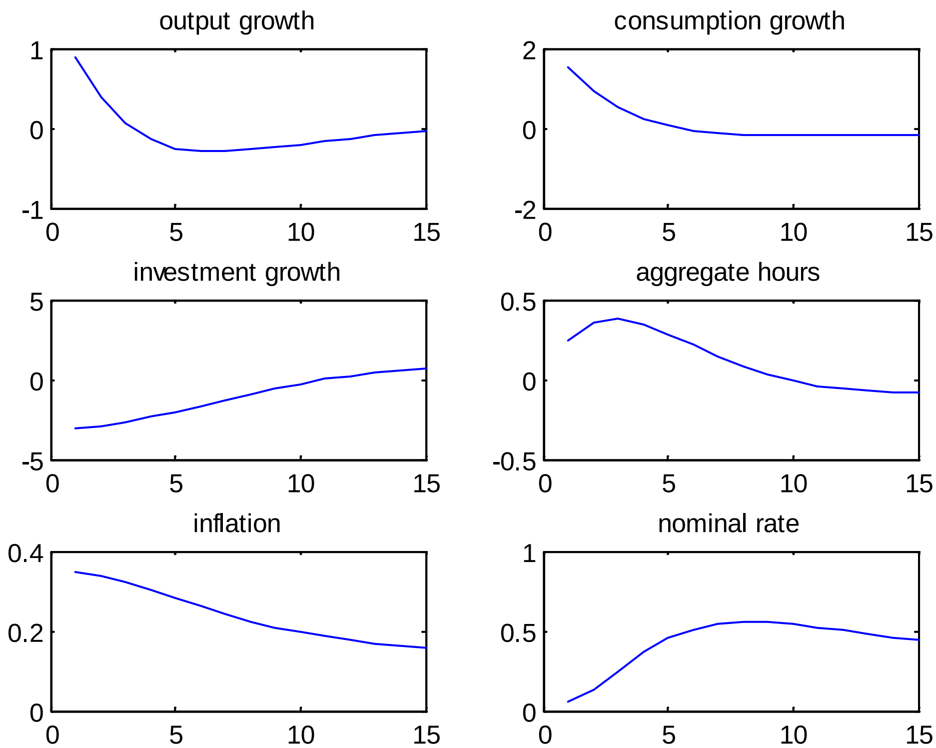
Impulse Response to Leisure Shock



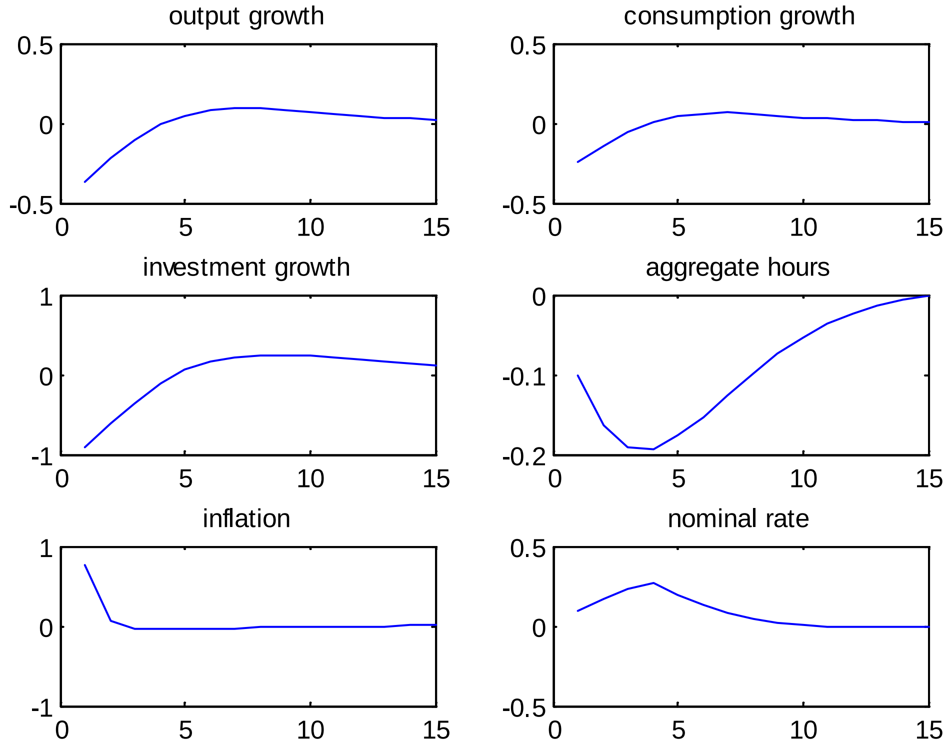
Impulse Responses to MEI Shock



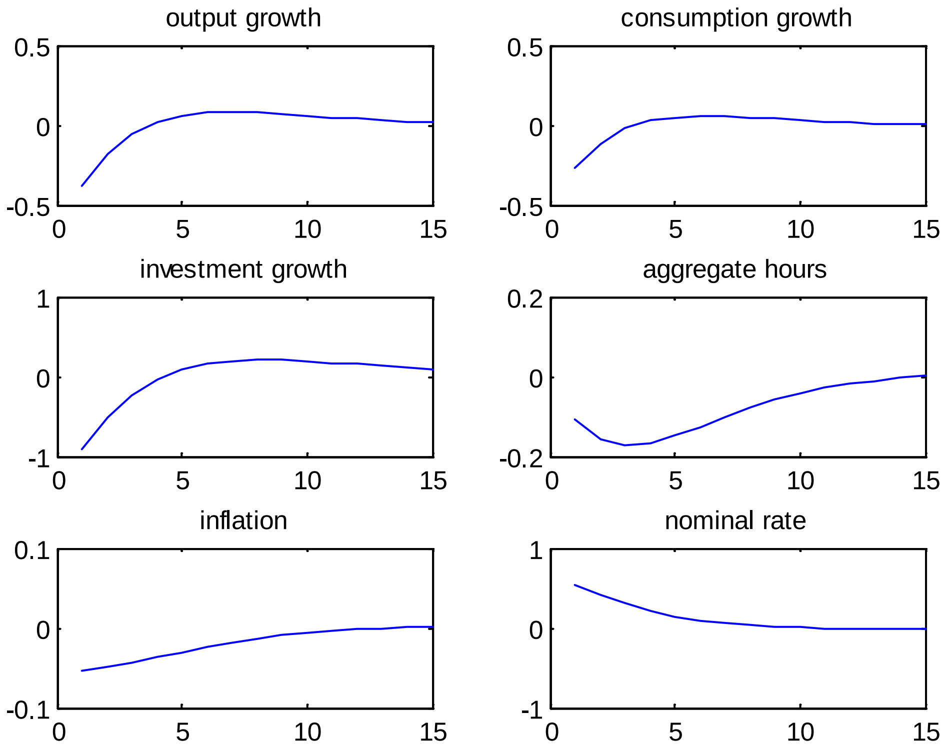
Impulse Responses to Financial Shock



Impulse Responses to Price Markup Shock



Impulse Responses to Unanticipated Monetary Policy Shock



Impulse Responses to Govt Spending Shock