BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

FOMC SECRETARIAT

Date: September 11, 2017

To: Federal Open Market Committee

From: Brian F. Madigan

Subject: Supporting Documents for DSGE Models Update

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

The Current Outlook in EDO: September 2017 FOMC Meeting Class II FOMC – Restricted (FR)

Taisuke Nakata*

September 7, 2017

1 The EDO Forecast from 2017 to 2020

The EDO models forecast is conditional on data through the second quarter of 2017 and on a preliminary Tealbook forecast for the third quarter of 2017.

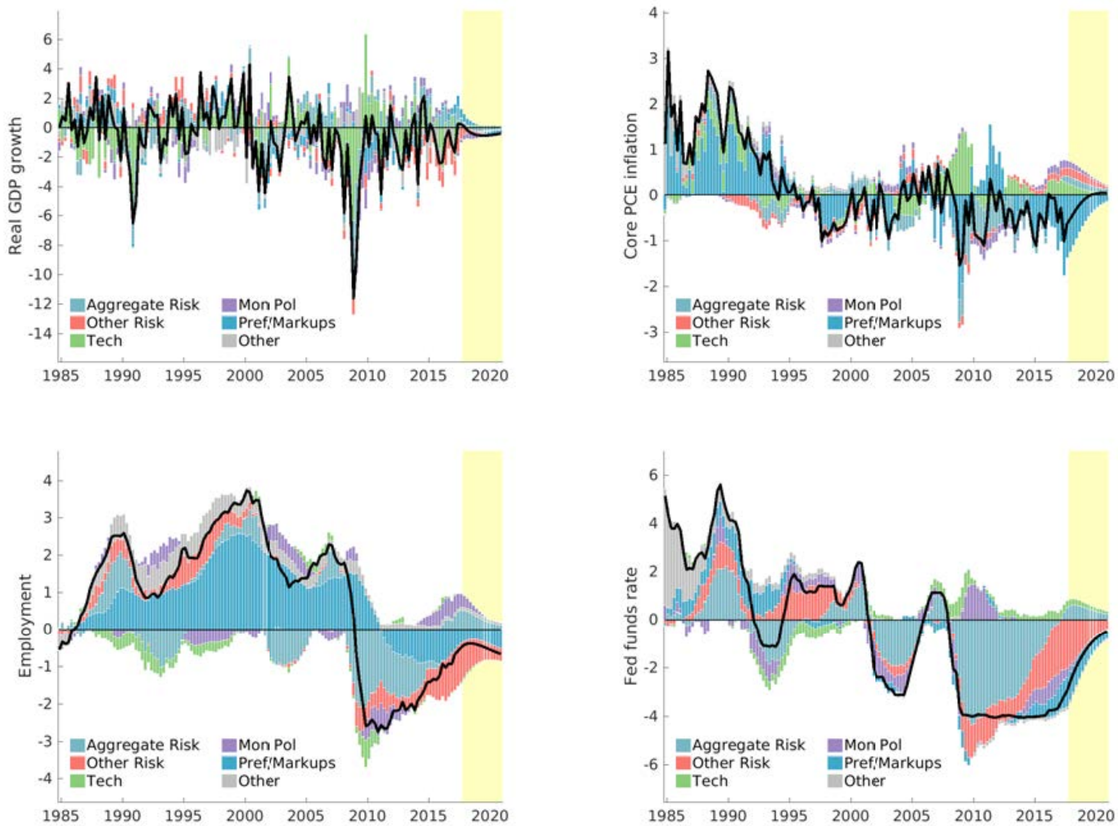
Real GDP growth is 2.7 percent on average over the projection horizon, a bit below its long-run value of 3 percent. Inflation reaches the Committees 2 percent objective in the third quarter of 2019 and then slightly overshoots the target thereafter. Below-trend real GDP growth is driven by the slow fading of positive contributions from favorable aggregate demand conditions and accommodative monetary policy. For inflation, the EDO model interprets the weakness in inflation over the past few years as driven by negative wage markup shocks and expects them to dissipate gradually over the projection horizon.

The output gap is estimated to be currently negative 1.2 percent. The output gap closes very slowly and remains at negative 0.2 percent by the end of 2020. The real natural rate of interest is projected to increase from 0.6 percent in the third quarter of 2017 to 1.9 percent at the end of 2020, 0.2 percentage points below its steady-state value of 2.1 percent. According to the EDO model, capital-specific risk premium shocks—inferred from weak investment over the past several years—have been holding down the output gap and the real natural rate. As these shocks slowly dissipate, the output gap closes and the real natural rate rises.

Consistent with the gradual return of inflation and the output gap to their long-run values, the federal funds rate is projected to increase gradually over the forecast horizon, reaching 3.8 percent by the end of 2020. At the end of the projection horizon, the federal funds rate is still somewhat below its long-run value of 4.1 percent, reflecting the inertia in the policy rule and the persistently negative output gap even at the end of the projection horizon.

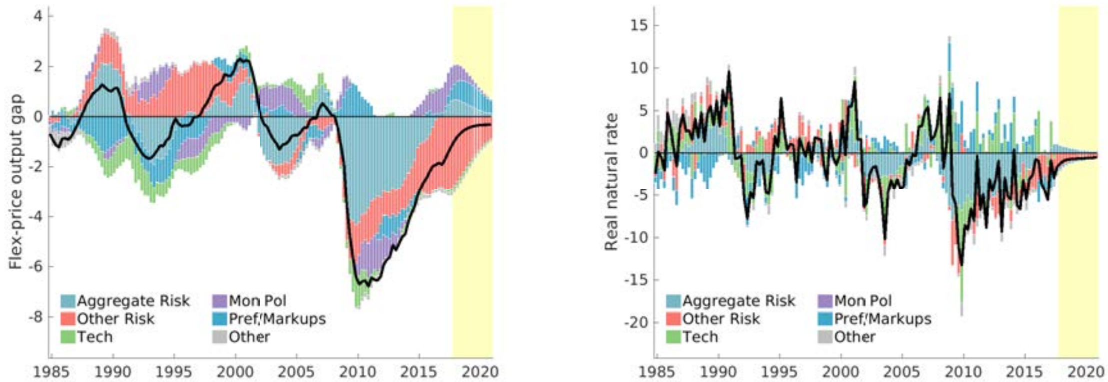
*Taisuke Nakata is affiliated with the Division of Research and Statistics of the Federal Reserve Board. Sections 2 and 3 contain background material on the EDO model, as in previous rounds. These sections were co-written with Hess Chung and Jean-Philippe Laforte.

Figure 1: Recent History and Forecasts



The EDO models projection of real GDP growth in this round is slightly faster for the next two years than it was in June 2017. The upward revision in the real GDP growth projection is driven by more negative markup shocks inferred from weaker-than-expected wage growth as well as downward revisions in the historical real wage series associated with the BEAs annual data revisions. Core PCE inflation is, on average, 30 basis points lower over the forecast horizon in this round than in June, also due to these more negative markup shocks. In the near term, the output gap has revised down slightly since June, but it is higher in the medium term. The projection of the real natural rate of interest is essentially unchanged from June. And, consistent with the lower inflation path, the path of the federal funds rate is lower this round than in June.

Figure 2: Recent History and Forecasts: Latent Variables



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]

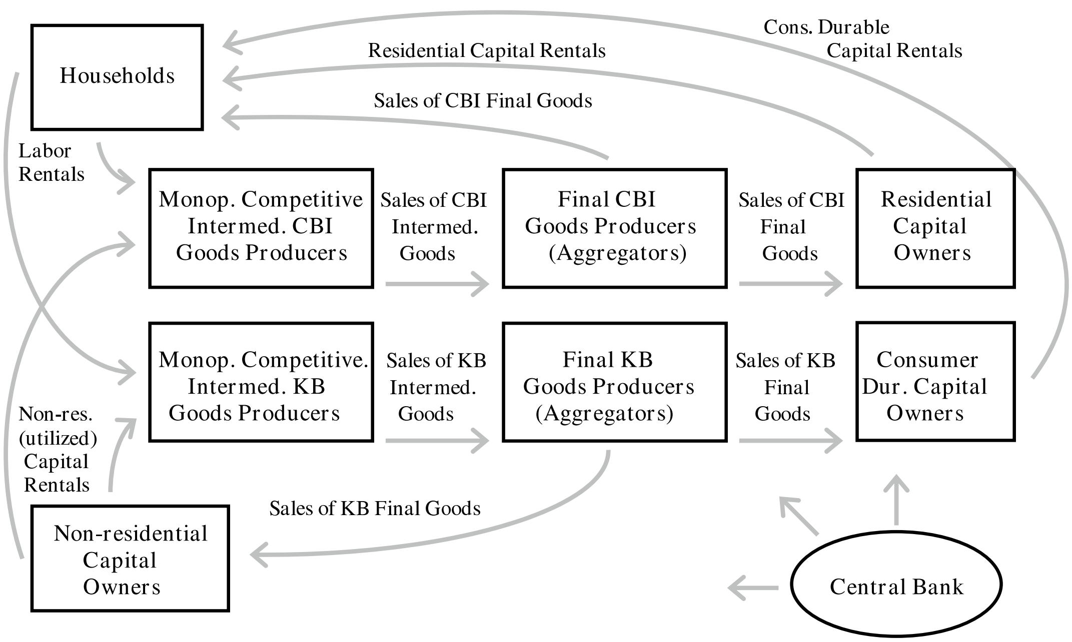
Specifically, the model possesses two final good sectors in order to capture key long-run growth facts and to differentiate between the cyclical properties of different categories of durable expenditure (for example, housing, consumer durables, and nonresidential investment). For example, technological 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 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

[1] Chung, Kiley, and Laforte (2010) provide much more detail regarding the model specification, estimated parameters, and model properties.

Figure 3: Model Overview



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 (2011).
- 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 non-durables 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.

2.3 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.

[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 $\nu \in (0, 1]$.

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.

[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.

As emphasized by Gali (2011), 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. 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

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

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

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

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 top right 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 $\bar{R}_t$

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

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 r^y and r^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).

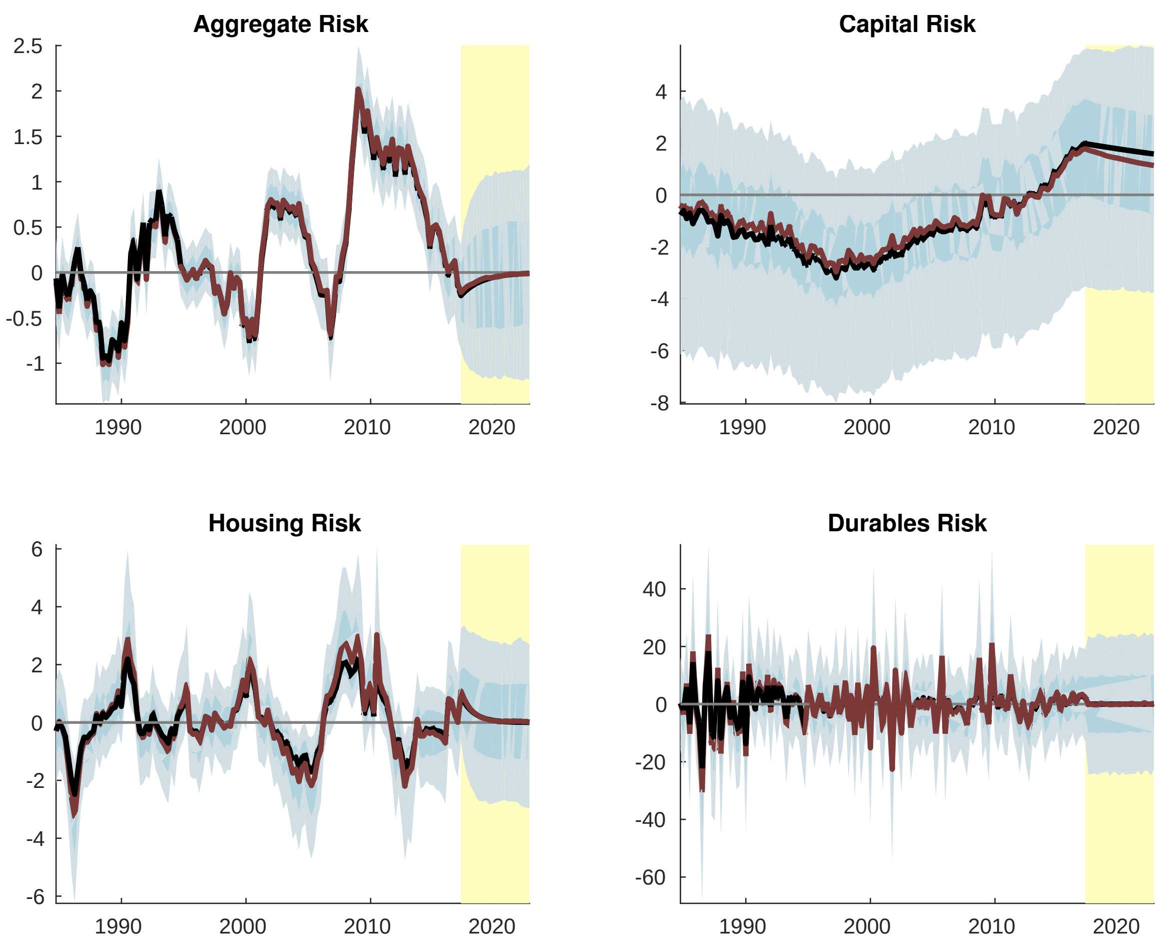
Our implementation adds measurement error processes to the likelihood implied by the model for all of the observed series used in estimation except the short-term nominal interest rate series.

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.

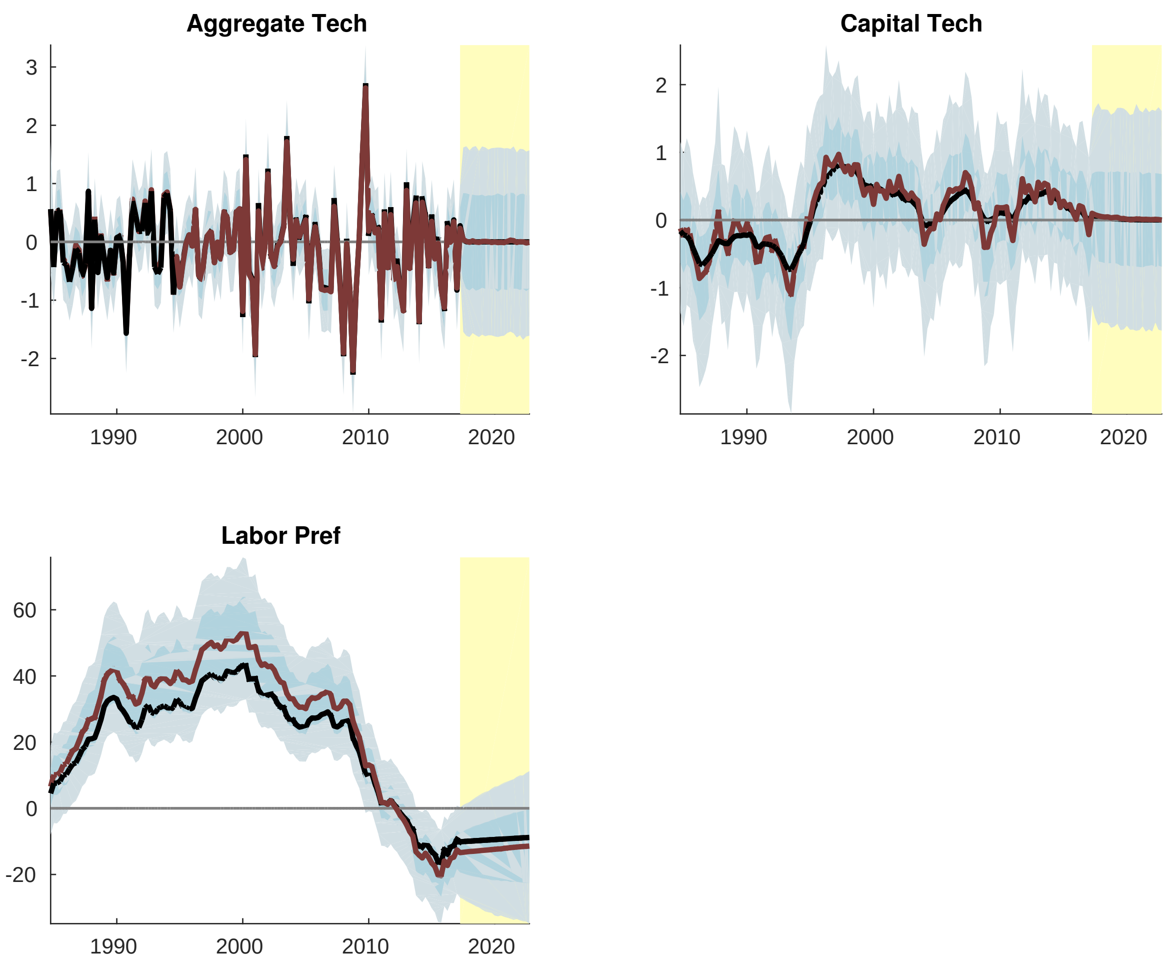
Of course, these stories from a glance at the exogenous drivers, yield applications for alternative versions of the EDO model and future model enhancements. For example, the exogenous risk premiums can easily be made to have an endogenous component, following the approach of Bernanke, Gertler, and Gilchrist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



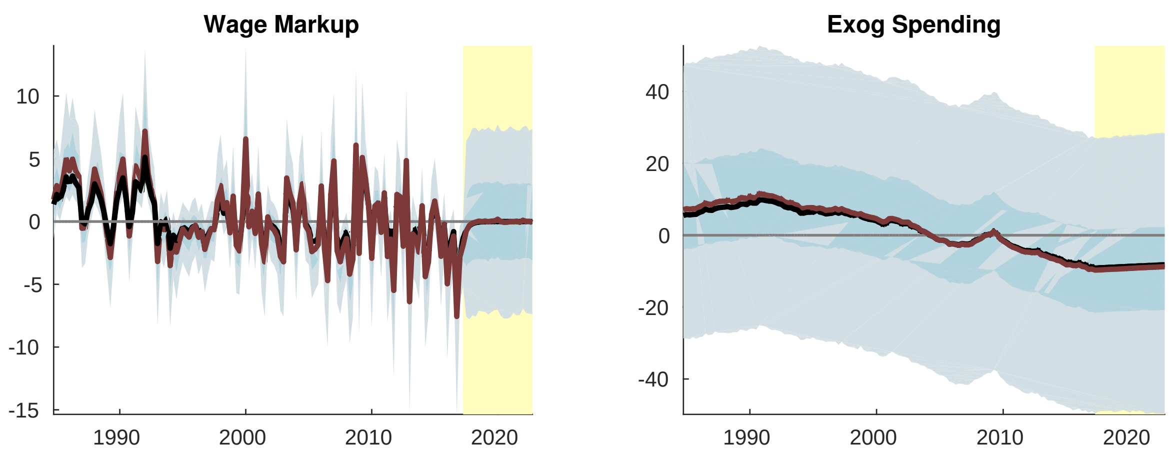
Black line: modal parameters. Red line: posterior median. Dark blue intervals: 68 percent credible set. Light blue intervals: 95 percent credible set.

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.

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.

[Boivin, Kiley, and Mishkin (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.

[Chung, Kiley, and Laforte (2010)] Chung, H., M. Kiley, and J.P. Laforte. 2010. Documentation of the Estimated, Dynamic, Optimization-based (EDO) model of the U.S. economy: 2010 version. Finance and Economics Discussion Series, 2010-29. Board of Governors of the Federal Reserve System (U.S.).

[Edge, Kiley, and Laforte (2008)] Edge, R., M. Kiley, and J.P. Laforte. 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., M. Kiley, and J.P. Laforte. 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, J. 2011. The Return Of The Wage Phillips Curve. Journal of the European Economic Association, vol. 9(3), pages 436-461.

[Gali, Smets, and Wouters (2011)] Gali, J., F. Smets, and R. Wouters. 2011. Unemployment in an Estimated New Keynesian Model. NBER Macroeconomics Annual vol. 26(1), pages 329-360.

[Smets and Wouters (2007)] Smets, F., and R. Wouters. 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.

New York Fed DSGE Model: Research Directors Draft

September 11, 2017

Summary of the Forecasts

The New York Fed model forecasts are obtained using data released through 2017Q2, augmented for 2017Q3 with the New York Fed staff forecasts (as of August 30) for real GDP growth and core PCE inflation, and with values of the federal funds rate, the 10-year Treasury yield and the spread between Baa corporate bonds and 10-year Treasury yields based on 2017Q3 averages up to August 30.

The model projects real GDP growth of 2.3 percent in 2017, which is higher than the June forecast of 2.0 percent growth for 2017. Growth falls back to 2.0 percent in 2018 and 2019, in line with the previous quarter's forecast. The projections of inflation have been revised upwards slightly at all horizons, sitting about 0.1 percentage point higher than the model's projection in June. Inflation is projected to be 1.4 percent in 2017, dipping slightly to 1.3 percent in 2018, and increasing slightly thereafter to 1.5 percent in 2019 and 1.7 percent in 2020, still below the committee's target. These projections are slightly higher than the June forecasts, which indicated 1.3, 1.3, 1.4 and 1.6 percent for 2017, 2018, 2019 and 2020 respectively.

The current output gap is estimated to be -0.9 percent and is projected to slowly shrink to -0.6 percent by the end of 2020. Compared to June, both the near-term and long-term forecasts have been revised upwards with the longer-term forecasts seeing larger improvements. While the 2017 forecast was revised up only 0.1 percentage points from June, the forecasts for 2018, 2019 and 2020 saw a larger revision, increasing from a June forecast of -1.1 percent for all three years to the current forecast of -0.8 percent for 2018 and -0.6 percent for 2019 and 2020. The natural rate of interest is projected to be 0.5 percent at the end of 2017, the same as in June. In fact, the projected path of the natural rate remains unchanged from the June forecast.

The projections for all the variables are surrounded by notable uncertainty. For instance, the range of 68 percent probability interval for GDP growth is as large as 1.9 percentage points in 2017, from 1.3 to 3.2 percent, and widens over the forecast horizon, reaching 5.6 percentage points in 2020, from -0.8 to 4.8 percent. Similarly, the 68 percent probability intervals for inflation range from 1.2 to 1.6 percent in 2017 and from 0.4 to 2.9 percent in 2020.

The model attributes the temporarily higher level of real GDP growth in 2017 to continued favorable financial conditions (measured by the financial and marginal efficiency of investment shocks) and to a positive aggregate demand shock, although these were hampered by low TFP growth. The model attributes the below target path for inflation partly to persistently low wage and price markups. Although the forecast for the natural rate of interest did not change since June, the model continues to project that improving financial conditions will gradually return the natural rate to its long run level and contribute to reducing the output gap. A somewhat more accommodative monetary policy than anticipated in June also contributes to reducing the output gap.

Finally, the federal funds rate is projected to increase gradually over the forecast horizon, reaching 2.9 percent by the end of 2020. The federal funds rate remains below its long run level of 4 percent throughout the forecast horizon owing to persistence in the interest rate rule, persistently low inflation and a lingering output gap. The projected path is shallower than the Septmber Tealbook forecast.

The Model and Its Transmission Mechanism

General Features of the Model

The New York Fed 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 New York

Fed 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, intermediate-goods producing firms, banks, entrepreneurs, capital-goods producers 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.

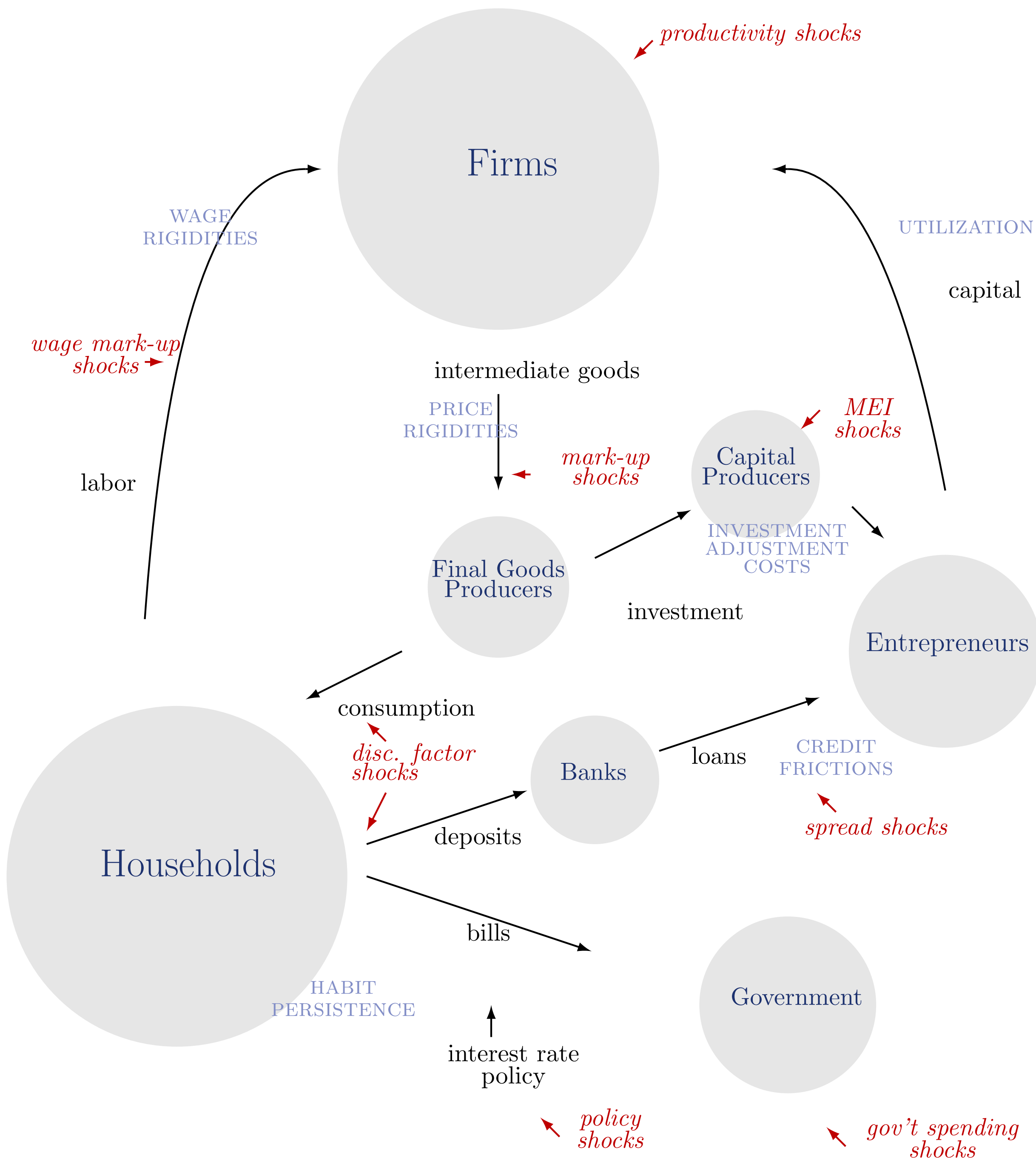
Monopolistically competitive firms produce intermediate goods, which a competitive firm aggregates into the single final good that is used for both consumption and investment. The production function of intermediate producers is subject to "total factor productivity" (TFP) shocks, which affect both the 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 a sudden desire by households to cut down on their consumption and save more. This shift may capture the fact that households want to reduce their debt level, or 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 fall in output growth (top left panel), hours worked (top right panel), and real wage growth. The implied reduction in marginal costs puts downward pressure on inflation (second and third rows). In addition, the discount factor shock implies an increase in the credit spread (fifth panel in left row), which weighs negatively on investment. Monetary policy typically attempts to mitigate the decline in activity and inflation by lowering the FFR, but it cannot fully offset the macroeconomic effects of 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. Figure 7 shows the impulse responses to a one-standard-deviation innovation in the spread shock. 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. Of course, the effects of this same shock on GDP growth, which roughly mirrors the change in the level of hours, are 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.

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 effect on output growth, but it drives hours down on impact. This negative response of hours is due to the presence of nominal rigidities, which prevent aggregate demand from expanding enough 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. 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 are less persistent. 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 few 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							
	2017		2018		2019		2020	
	Sep.	Jun.	Sep.	Jun.	Sep.	Jun.	Sep.	Jun.
Core PCE Inflation (Q4/Q4)	1.2 (0.9,1.6)	1.7 (1.2,2.2)	1.3 (0.4,2.2)	1.5 (0.5,2.4)	1.5 (0.4,2.5)	1.6 (0.4,2.7)	1.6 (0.4,2.8)	1.7 (0.4,2.9)
Real GDP Growth (Q4/Q4)	2.3 (0.9,3.6)	1.5 (−0.4,3.4)	2.0 (−0.8,4.5)	1.8 (−1.0,4.4)	2.0 (−0.8,4.7)	2.1 (−0.7,4.8)	2.1 (−0.8,4.8)	2.2 (−0.7,4.9)
Real Natural Rate (Q4)	0.5 (−1.0,2.0)	0.4 (−1.1,2.0)	0.9 (−0.8,2.6)	0.9 (−0.9,2.6)	1.1 (−0.7,3.0)	1.1 (−0.8,2.9)	1.2 (−0.7,3.2)	1.1 (−0.7,3.1)
Output Gap (Q4)	−0.9 (−2.3,0.6)	−1.3 (−3.0,0.4)	−0.7 (−3.3,1.5)	−1.4 (−4.1,1.0)	−0.6 (−4.0,2.2)	−1.4 (−4.8,1.7)	−0.5 (−4.4,2.7)	−1.3 (−5.1,2.1)

	Conditional Forecast							
	2017		2018		2019		2020	
	Sep.	Jun.	Sep.	Jun.	Sep.	Jun.	Sep.	Jun.
Core PCE Inflation (Q4/Q4)	1.4 (1.2,1.6)	1.3 (0.9,1.6)	1.3 (0.5,2.2)	1.3 (0.3,2.2)	1.5 (0.4,2.6)	1.4 (0.3,2.6)	1.7 (0.4,2.9)	1.6 (0.3,2.8)
Real GDP Growth (Q4/Q4)	2.3 (1.3,3.2)	2.0 (0.4,3.4)	2.0 (−0.8,4.4)	2.0 (−0.9,4.5)	2.0 (−0.8,4.7)	2.0 (−0.8,4.8)	2.1 (−0.8,4.8)	2.1 (−0.7,4.9)
Real Natural Rate (Q4)	0.5 (−0.9,2.0)	0.5 (−1.0,2.0)	0.9 (−0.9,2.6)	0.9 (−0.8,2.7)	1.1 (−0.7,3.0)	1.1 (−0.8,3.0)	1.2 (−0.7,3.2)	1.2 (−0.7,3.1)
Output Gap (Q4)	−0.9 (−2.2,0.5)	−1.0 (−2.7,0.6)	−0.8 (−3.2,1.4)	−1.1 (−3.8,1.3)	−0.6 (−3.9,2.1)	−1.1 (−4.6,1.9)	−0.6 (−4.3,2.6)	−1.1 (−5.0,2.3)

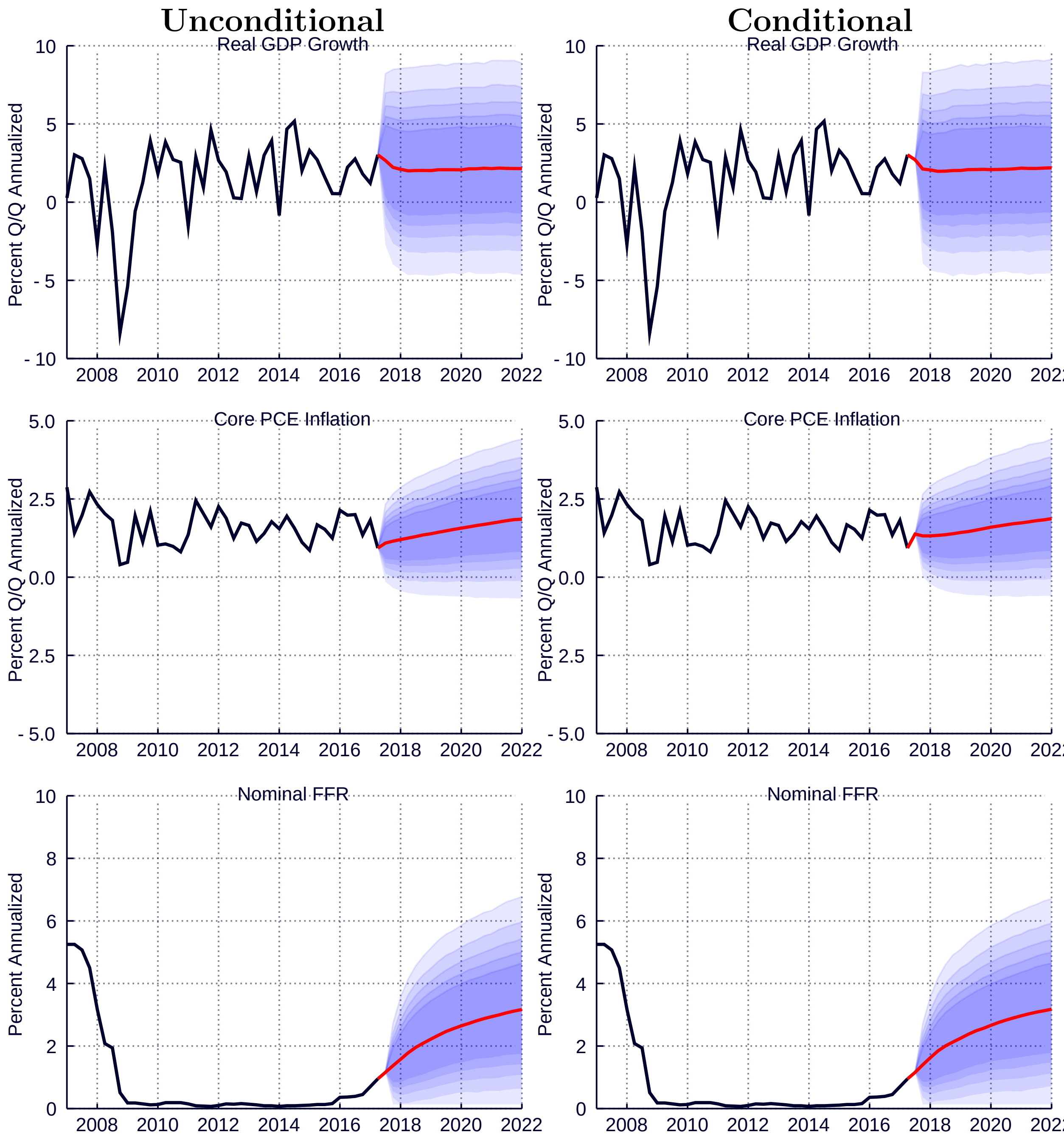
*The unconditional forecasts use data up to 2017Q2, the quarter for which we have the most recent GDP release, as well as the federal funds rate, 10-year Treasury yield, and spreads data for 2017Q3. In the conditional forecasts, we further include the 2017Q3 New York Fed projections for GDP growth and core PCE inflation as additional data points. Numbers in parentheses indicate 68 percent probability intervals.

The table above presents annual forecasts for real GDP growth, core PCE inflation, the real natural rate, and the output gap for 2017-2020, with 68 percent probability intervals. We include two sets of forecasts. The *unconditional* forecasts use data up to 2017Q2, the quarter for which we have the most recent GDP release. These forecasts also use federal funds rate, 10-year Treasury yield, and spreads data for 2017Q3 by taking the average realizations for the quarter up to the forecast date. In the *conditional* forecasts, we further include the 2017Q3 New York Fed staff projections as of August 30 for GDP growth (2.7 percent) and core PCE inflation (1.4 percent) as additional data points. Treating the 2017Q3 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 2017 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 50, 60, 70, 80 and 90 percent probability intervals for the forecasts, reflecting both parameter and shock uncertainty. Figure 3 compares the current forecasts with the June forecasts. Our discussion will mainly focus on the conditional forecasts, which are those reported in the memo to the FOMC.

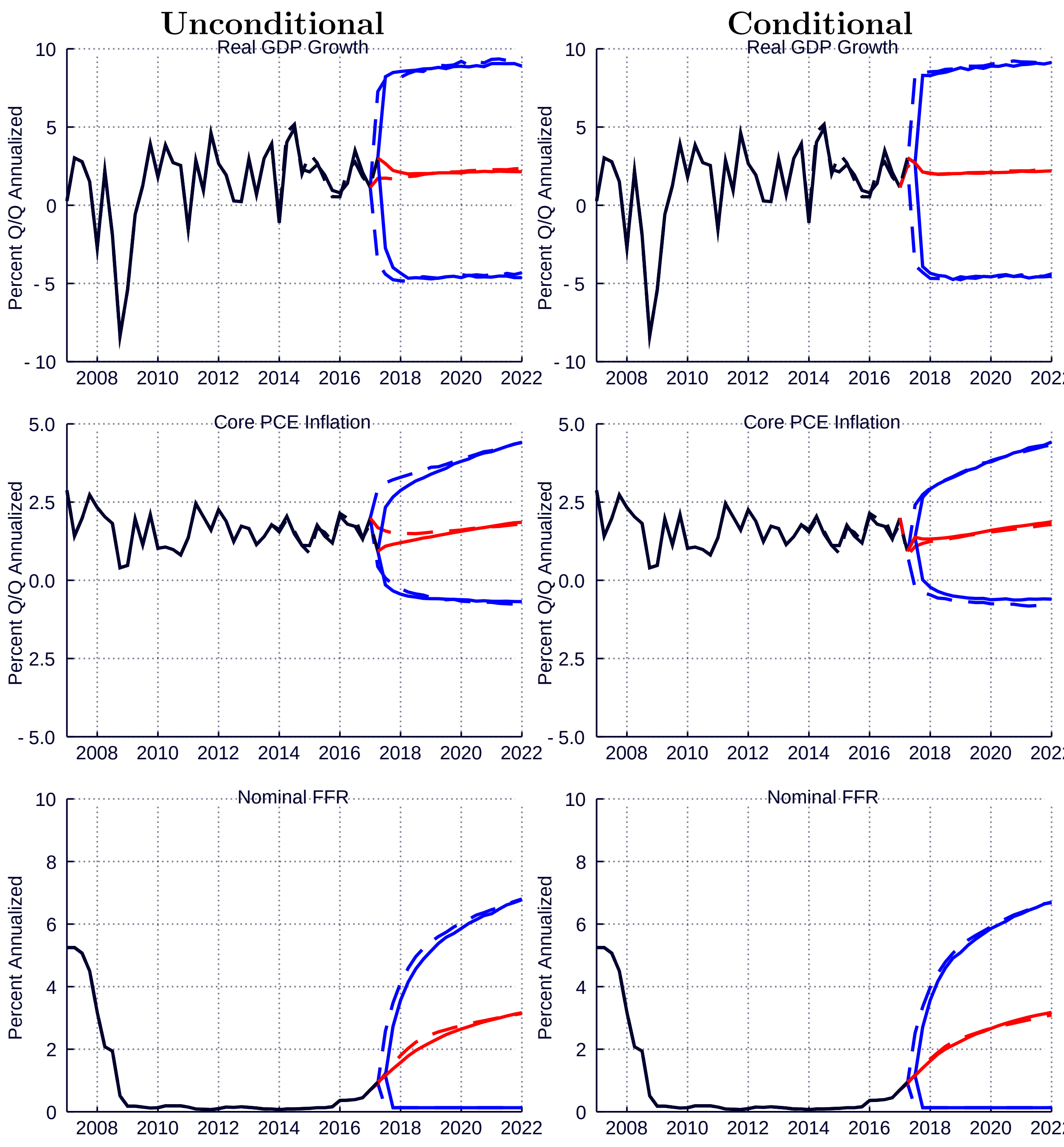
Relative to June, the conditional forecast predicts higher output growth in 2017, but similar growth in 2018 and beyond. Over the medium to longer term the model expects growth to remain steady at 2.0 percent from 2017 through 2019, rising slightly to 2.1 percent in 2020. The inflation projections rise slowly over the entire forecast horizon and are somewhat stronger than in June. The model sees inflation at 1.4 percent in 2017, dipping slightly to 1.3 percent in 2018, but steadily rising from then on through to 2020. The current output gap forecast is slightly smaller than the June forecast, with the output gap in 2017 forecasted to be -0.9 percent, compared to -1.0 percent in the June forecast. However, in the following years, the forecasted gap closes gradually from -0.8 percent in 2018 to -0.6 percent by 2020.

Figure 2: Forecasts



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 onwards. 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, since this is the variable featured in the model; in the forecasts, we add population growth to recover actual GDP growth). The bars represent the contribution of each shock to the deviation of the variable from steady state, computed as the counterfactual values (in deviations from the mean) obtained when all other shocks are zero. Some of the shocks have been aggregated in this decomposition. For example, the bars labeled "financial" (in purple) capture the effect of shocks to the spread as well as to the discount factor.

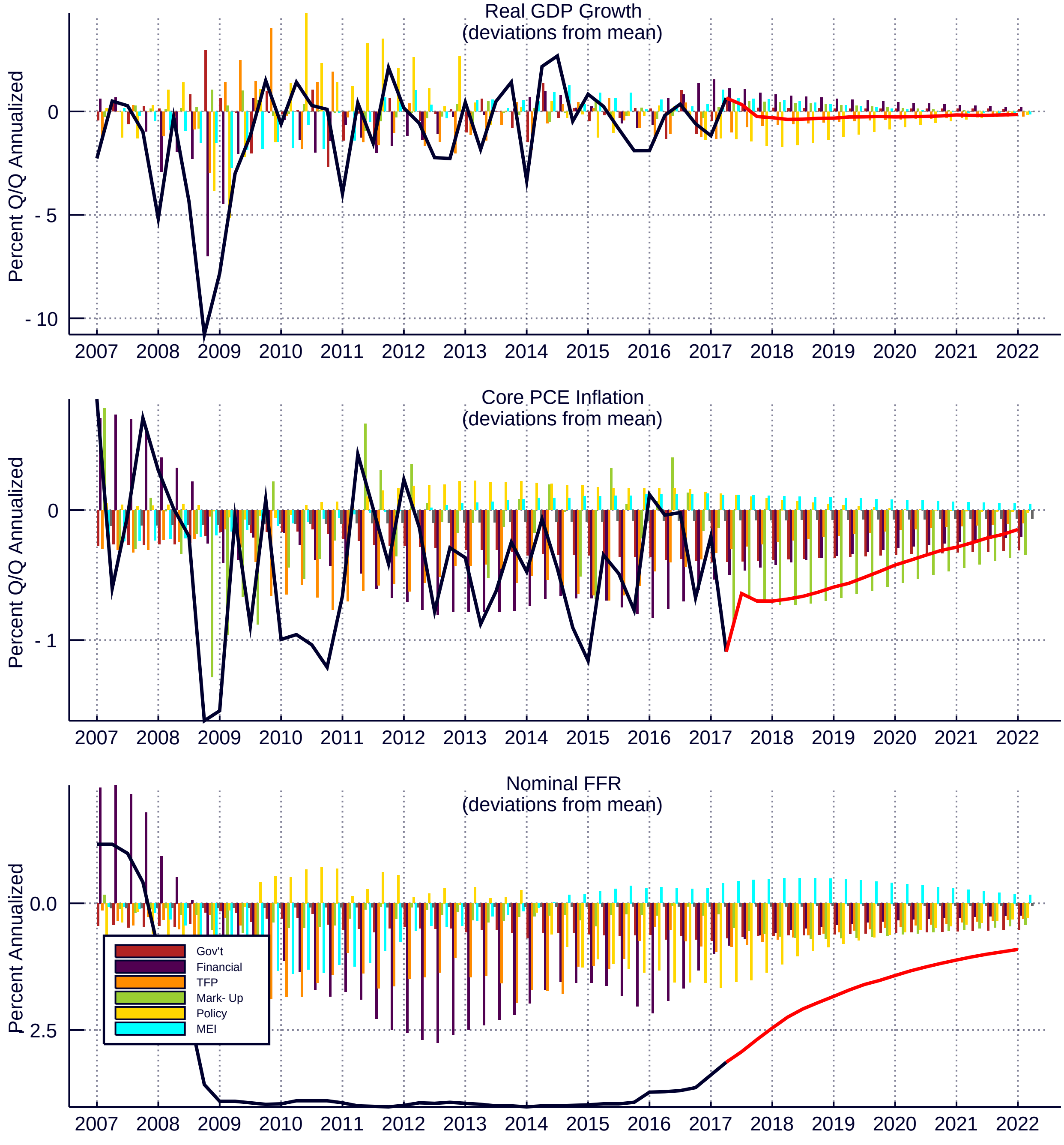
Seen through the lens of this decomposition, the evolution of the economy over the past few years and its forecast through 2020 can be described as follows. Between 2010 and 2014, persistent headwinds from the financial crisis, which are captured in the model by the financial (purple) and MEI (azure) shocks, held back the pace of the recovery. These sources of drag on the economy were also accompanied by a sequence of negative TFP shocks (orange bars), as was also apparent from the extraordinarily weak readings on both TFP and labor productivity over this period. During the course of 2014, the financial headwinds appeared to be abating, providing positive contributions to GDP growth that helped to lift it over its potential, hence also helping to close the output gap and increase the natural rate of interest (Figure 5). However, this improvement in financial conditions suffered a setback since the summer of 2015, pushing growth once again below steady state. More recently, both financial and MEI shocks are again estimated to be lifting growth, and to continue to do so through the forecast horizon, while productivity shocks will provide a somewhat offsetting force.

The oscillations in the contribution of financial shocks to economic developments are also evident in the historical decomposition of inflation, with the purple bars becoming negative after the financial crisis, and then contributing even more negatively beginning in 2011. Starting in 2017, these effects began to diminish very gradually, but are still projected to keep inflation below steady state throughout the forecast horizon. In addition, the model sees mark-up shocks (green bars), which capture the effect of exogenous changes in marginal costs such as those connected with fluctuations in commodity prices, as a further negative drag on inflation, an effect that is pronounced in early 2017 and is projected to persist throughout the forecast horizon. Beginning in 2011, inflation was also pulled down by negative government spending and TFP shocks.

In equilibrium, the negative impact of financial shocks on the economy is partly cushioned by the endogenous response of monetary policy, in the form of a reduction in the policy rate. In the case of financial shocks, for instance, this endogenous response is captured by the purple bars in the interest rate panel, which indicate that the Federal Funds rate was lowered throughout the recovery in response to the financial headwinds. In fact, this endogenous adjustment of the policy instrument was decreasing during 2014, when the effects of the headwinds were abating, but was dialed back up again in 2015 as financial conditions deteriorated again. In addition, the negative impact of exogenous shocks can be offset through expansionary monetary policy. In particular, forward guidance about the future path of the federal funds rate (captured by anticipated policy shocks whose effects are included in the yellow bars) played an important role in counteracting the financial headwinds between 2009 and 2013, 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, and is forecasted to drag down output growth in the forecasted periods.

Figure 5 shows the output gap–computed as the percent difference between output and its "natural" level, namely the one that would prevail in the absence of nominal rigidities and mark-up shocks–and the natural rate of interest through history. The natural rate of interest is projected to increase slowly over time, reflecting the continuing restraining effect of financial headwinds and lower productivity growth. This path for the real natural rate is roughly in line with that for the real policy rate, implying that monetary policy is not especially accommodative over the forecast horizon. However, relative to the model's projection in June, policy is expected to be slightly more accommodative in the near term, as indicated by the modest gap between the ex-ante real interest rate and the real natural rate in 2017. The model's estimate of the output gap suggests that slack persists and will be absorbed only gradually over time. This measure of underutilization of resources also reflects low marginal costs of production for firms, a key driver of the inflation projections. The model's 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. However, relative to the June forecast, the output gap is expected to close somewhat faster.

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

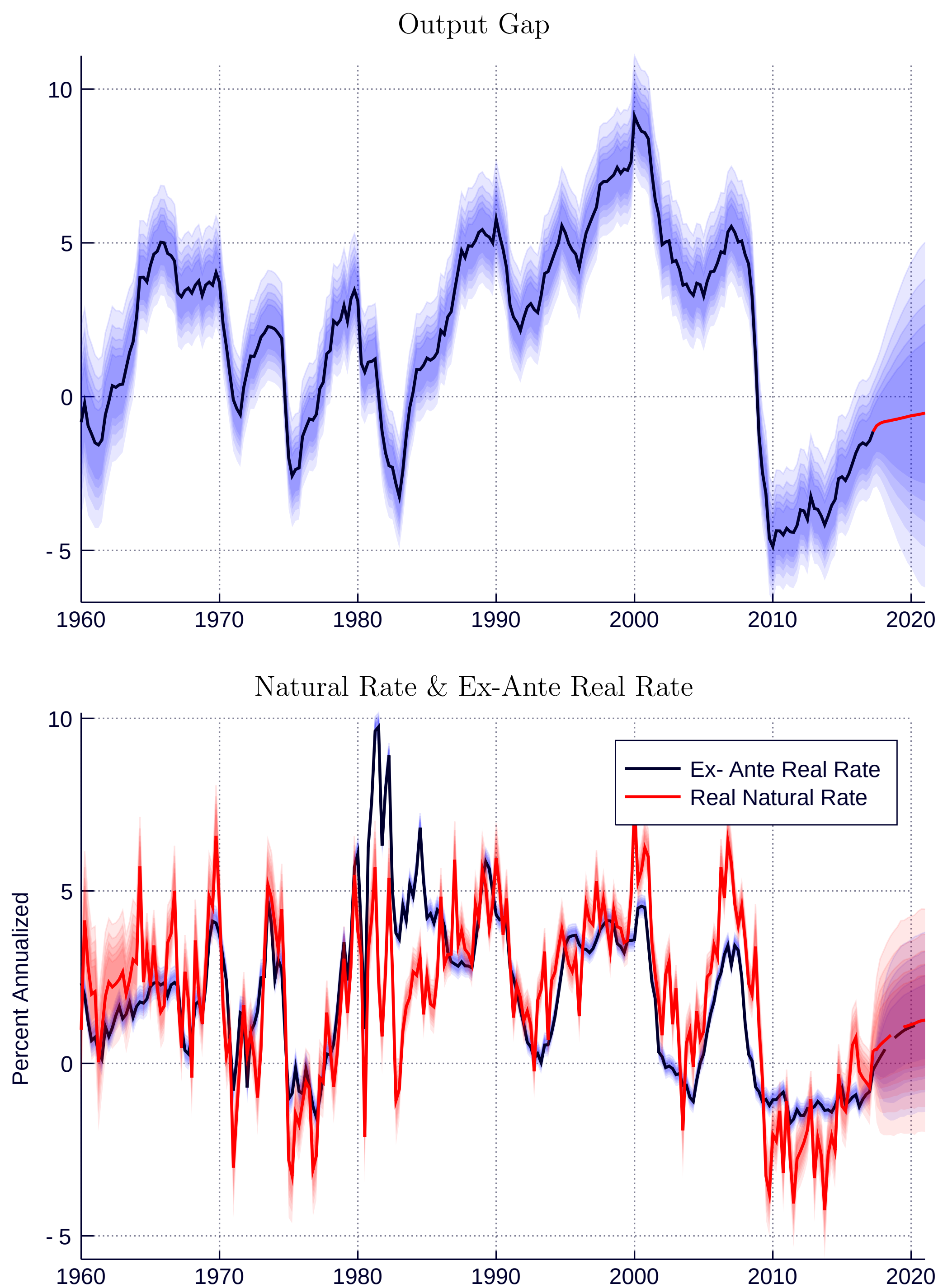


Figure 6: Responses to a Discount Factor Shock

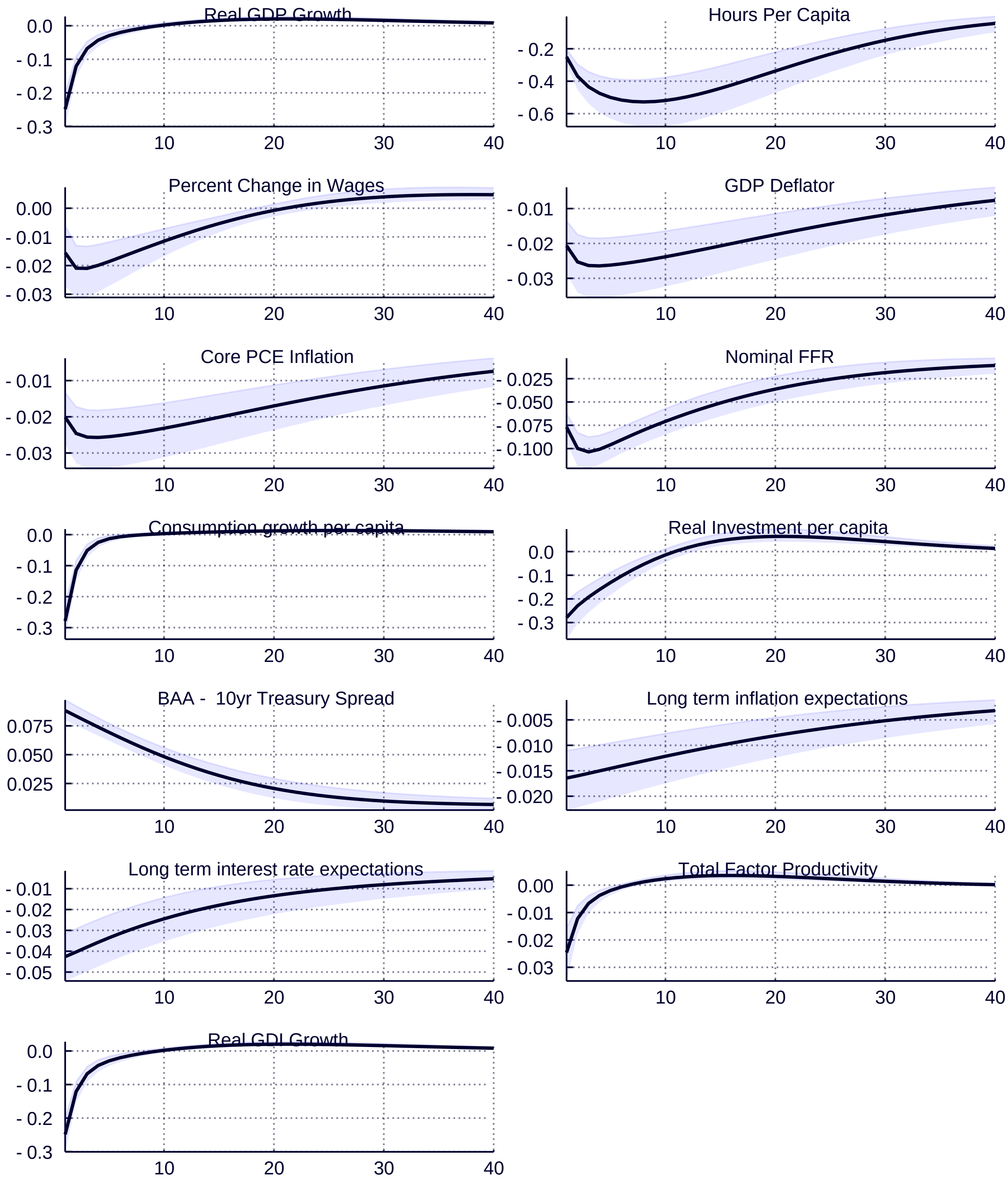


Figure 7: Responses to a Spread Shock

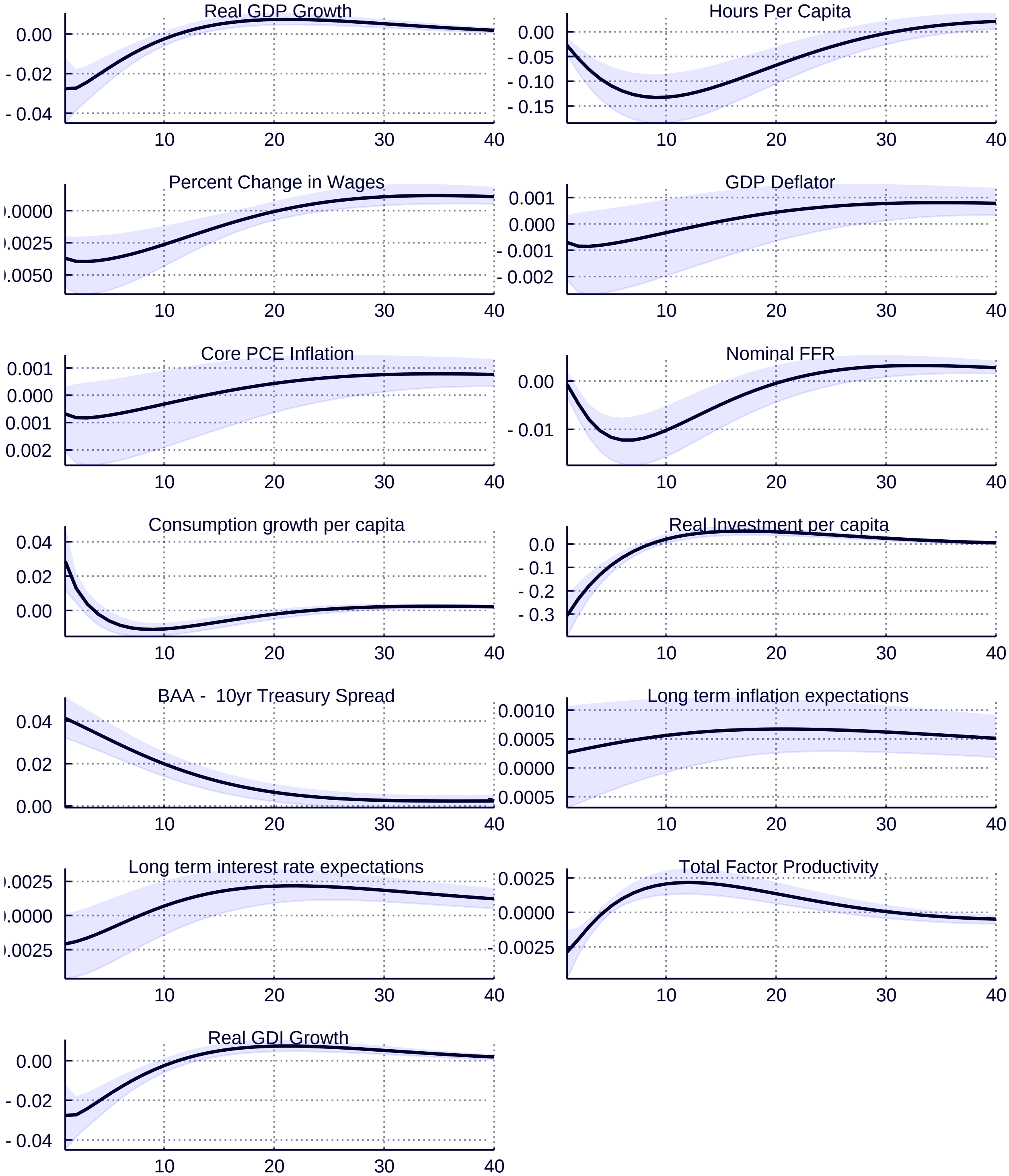


Figure 8: Responses to an MEI Shock

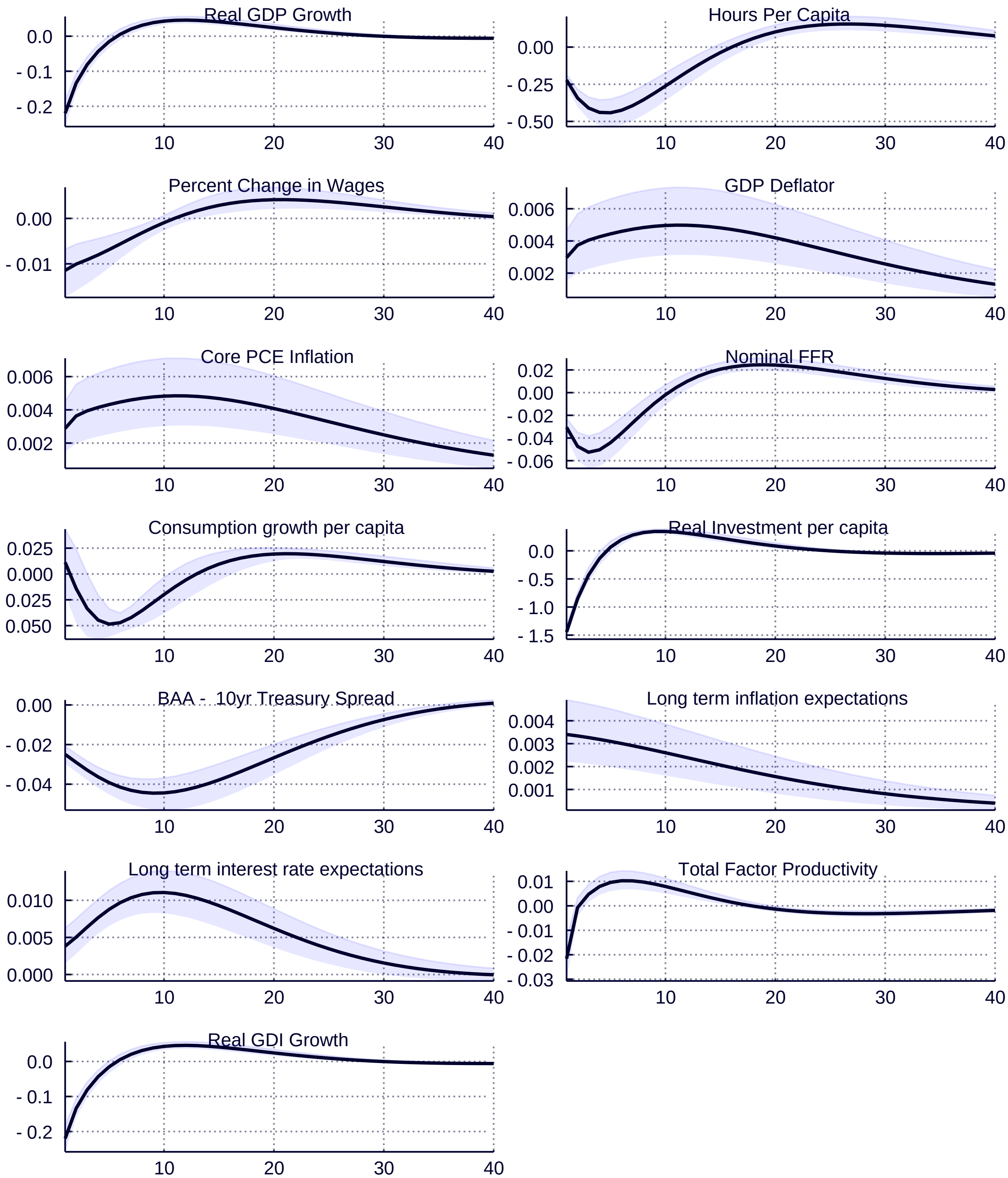


Figure 9: Responses to a TFP Shock

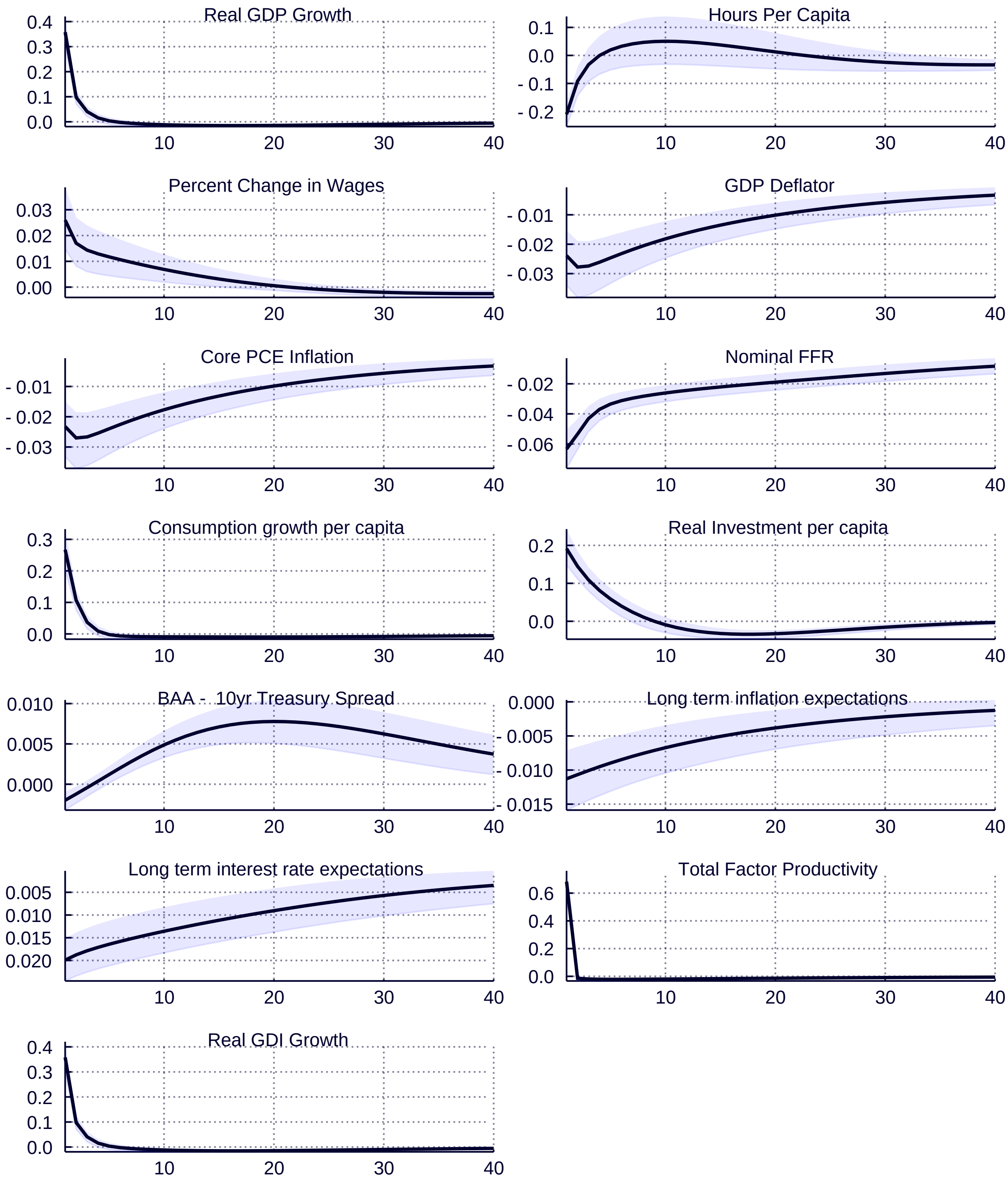


Figure 10: Responses to a Price Mark-up Shock

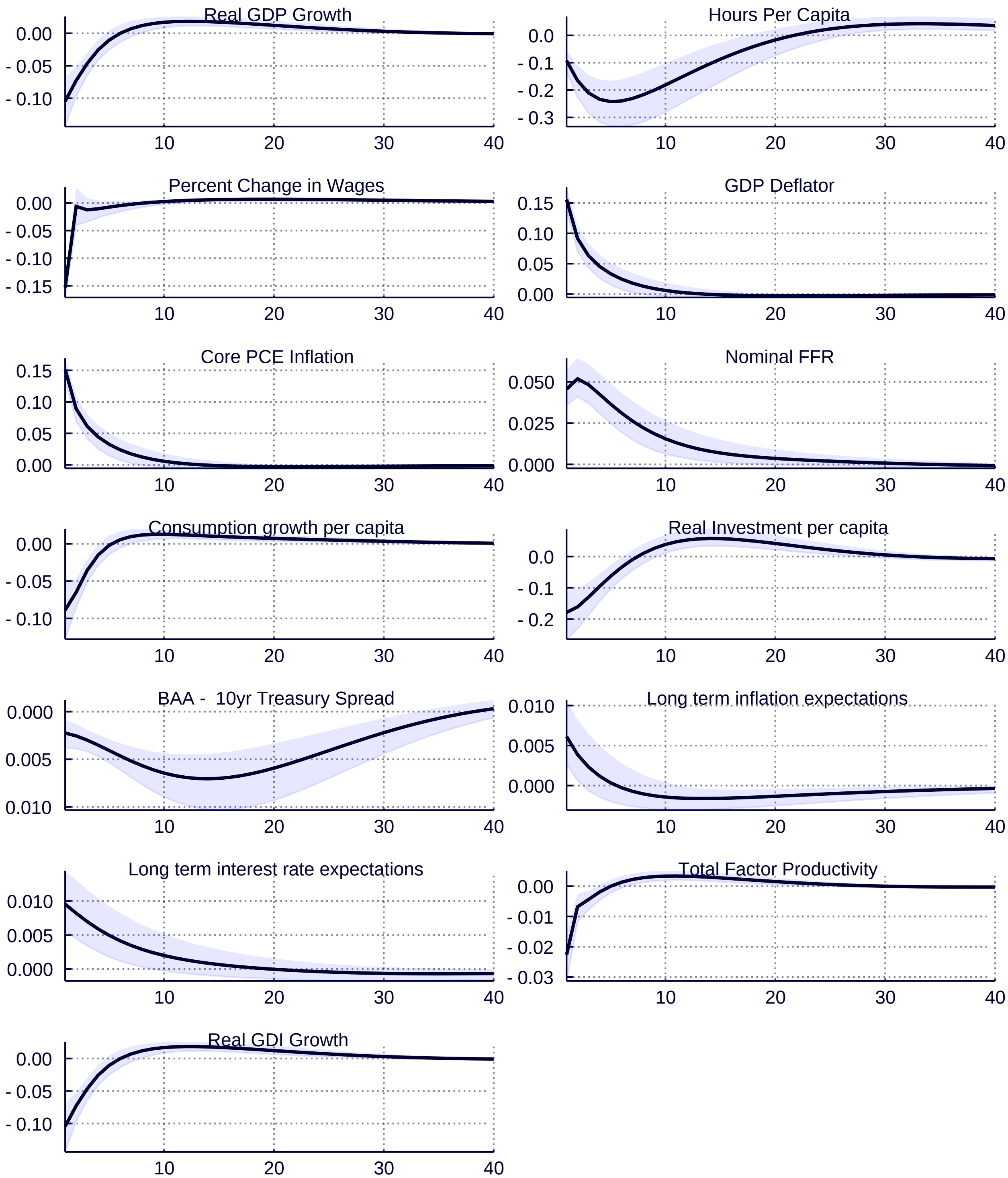
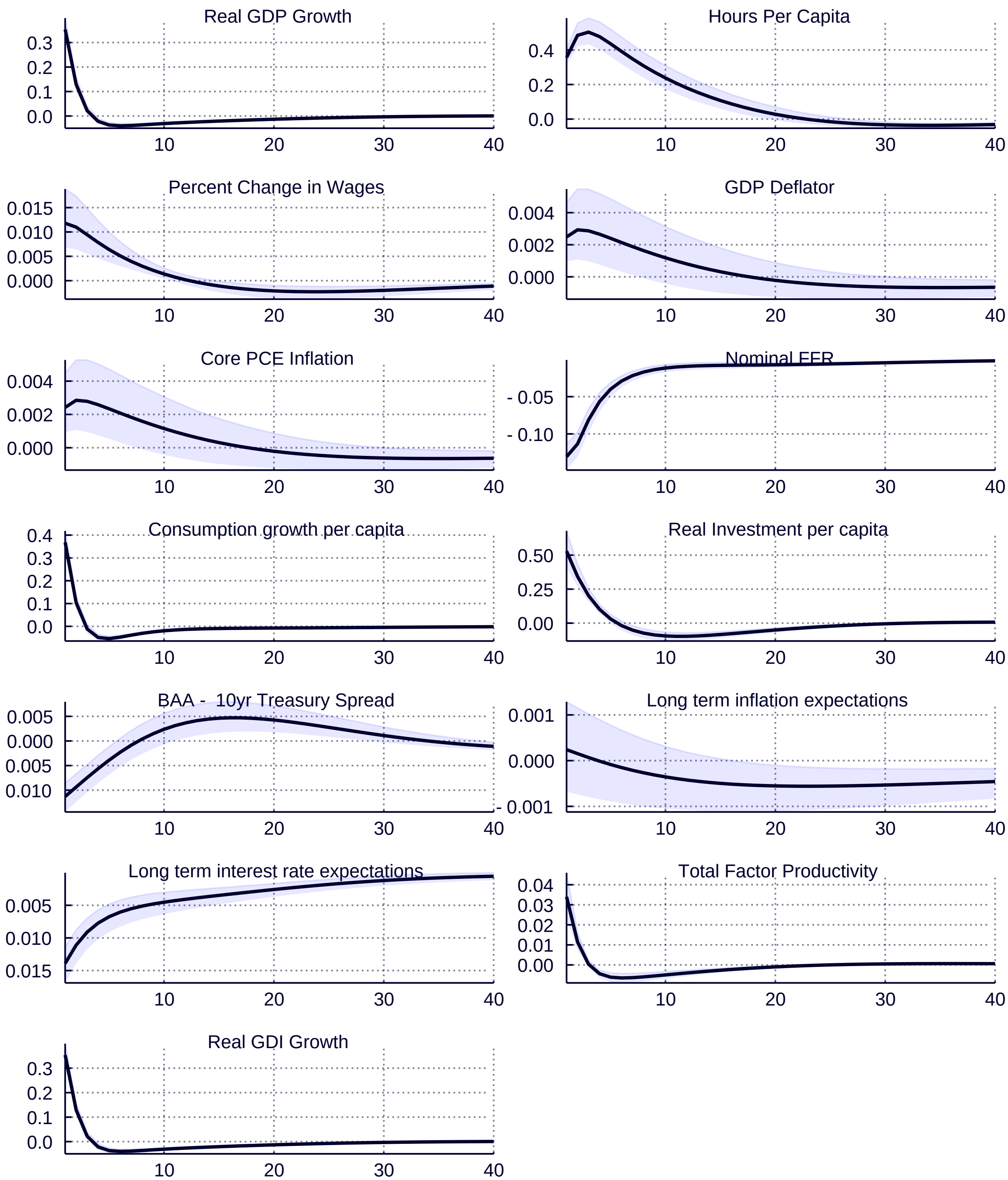


Figure 11: Responses to a Monetary Policy Shock



References

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999): "The Financial Accelerator in a Quantitative Business Cycle Framework," in *Handbook of Macroeconomics*, ed. by J. B. Taylor and M. Woodford, Amsterdam: North-Holland, vol. 1C, chap. 21, 1341–93.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113, 1–45.

Christiano, L. J., R. Motto, and M. Rostagno (2014): "Risk Shocks," *American Economic Review*, 104, 27–65.

Del Negro, M., M. P. Giannoni, and F. Schorfheide (2015): "Inflation in the Great Recession and New Keynesian Models," *American Economic Journal: Macroeconomics*, 7, 168–196.

Del Negro, M. and F. Schorfheide (2012): "DSGE Model-Based Forecasting," *Federal Reserve Bank of New York Working Paper*.

Laseen, S. and L. E. Svensson (2011): "Anticipated Alternative Policy-Rate Paths in Policy Simulations," *International Journal of Central Banking*, 7, 1–35.

Smets, F. and R. Wouters (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97, 586 – 606.

Detailed Philadelphia (PRISM) Forecast Overview

September 2017

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 a bit under 3.4 percent in mid-2018. Core PCE inflation edges up to reach 1.9 percent at the end of 2020. The funds rate rises to 1.4 percent in 2017Q4 and rises steadily to reach 3.5 percent at the end of 2020. The current gap between the level of output and its trend level remains significant in the estimated model and, absent any shocks, the model continues to predict a fairly 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 68 percent probability coverage intervals. The forecast uses data through 2017Q2 supplemented by a 2017Q3 nowcast. The model takes the 2017Q3 nowcast for output growth of 3 percent as given and the projection begins with 2017Q4. PRISM anticipates that output growth jumps to a near 3.4 percent pace in 2017Q4, with growth then remaining close to that pace through mid-2019. Overall, the growth forecast for this round is similar to the June projection. While output growth is fairly robust going forward, core PCE inflation stays contained and runs at a pace slightly below the 2 percent target over the next 3 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 by an estimated policy rule and the funds rate rises to 1.4 percent in 2017Q4, 2.3 percent in 2018Q4, 3.1 percent in 2019Q4, and 3.5 percent in 2020Q4. This path for the funds rate is somewhat weaker than in 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). Over the last few quarters, negative shocks to TFP have put downward pressure on real output growth. However, positive contributions from shocks to government spending, investment and hours worked were strong enough in 2017Q2 to push output growth to a slightly above-trend pace. As these shocks unwind, output growth maintains a steady pace of around 3.4 percent over the next few years. Over the course of the recession and recovery PRISM estimated a series 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 continue to rebound over the forecast horizon and so support higher output growth. Similarly, the unwinding of investment shocks contribute to output growth over the forecast horizon.

After strong performance in 2016, consumption growth (Figure 2d) pulled back to a below trend pace in early 2017 and is now projected to gradually rise toward trend over the next three years. An unwinding of investment shocks and higher interest rates dampen spending: spending returns to its trend pace at the end of 2020 as the effects of these shocks wane. Financial shocks that boost consumption in turn weaken investment growth (Figure 2d-e). However, strong investment shocks pushed investment growth to an above-trend pace in the second half of 2016 and into 2017. The model now forecasts above-trend growth in investment (gross private domestic + durable goods consumption) in 2018 as the gradual unwinding of MEI shocks (see Figures 2e and 3) are partially offset by the effects of financial shocks: the unwinding of the discount factor shocks leads to a downward pull on investment growth over the next three years.

The forecast for core PCE inflation continues to be 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. But 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 keep inflation close to, or slightly below, target over the next 3 years.

The federal funds rate is projected to rise fairly quickly over the forecast horizon. The model attributes the current level of the funds rate primarily 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 over the medium term, but as these shocks wane the funds rate gradually rises to 3.5 percent by the end of 2020.

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

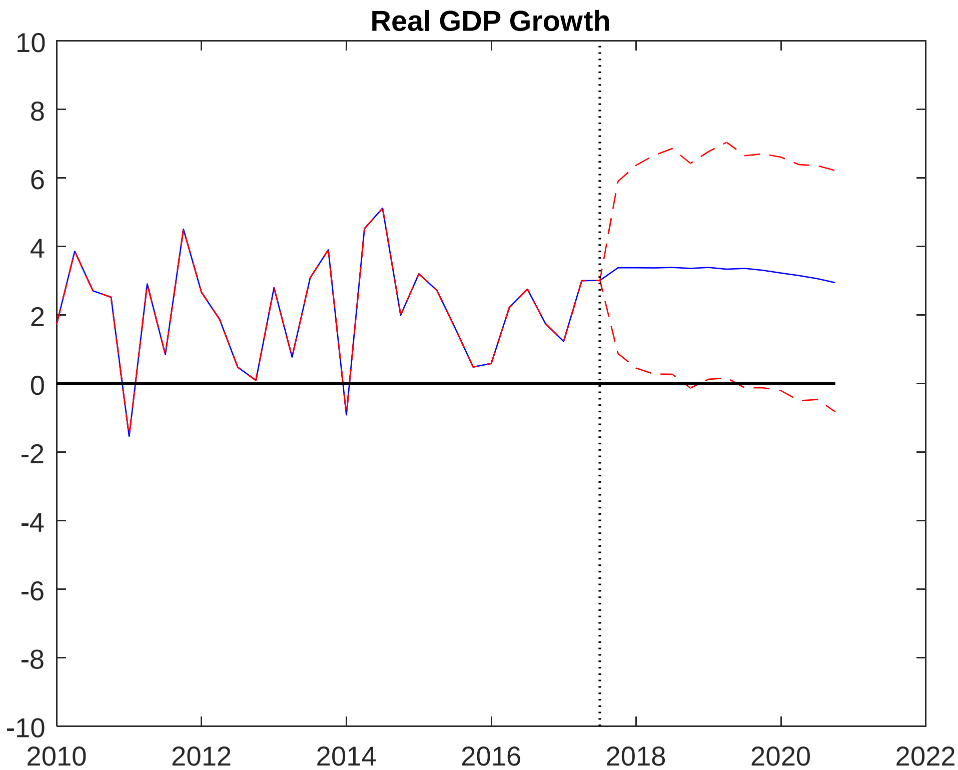

Real GDP Growth
10
8
6
4
2
0
-2
-4
-6
-8
-10
2010
2012
2014
2016
2018
2020
2022

Figure 1b

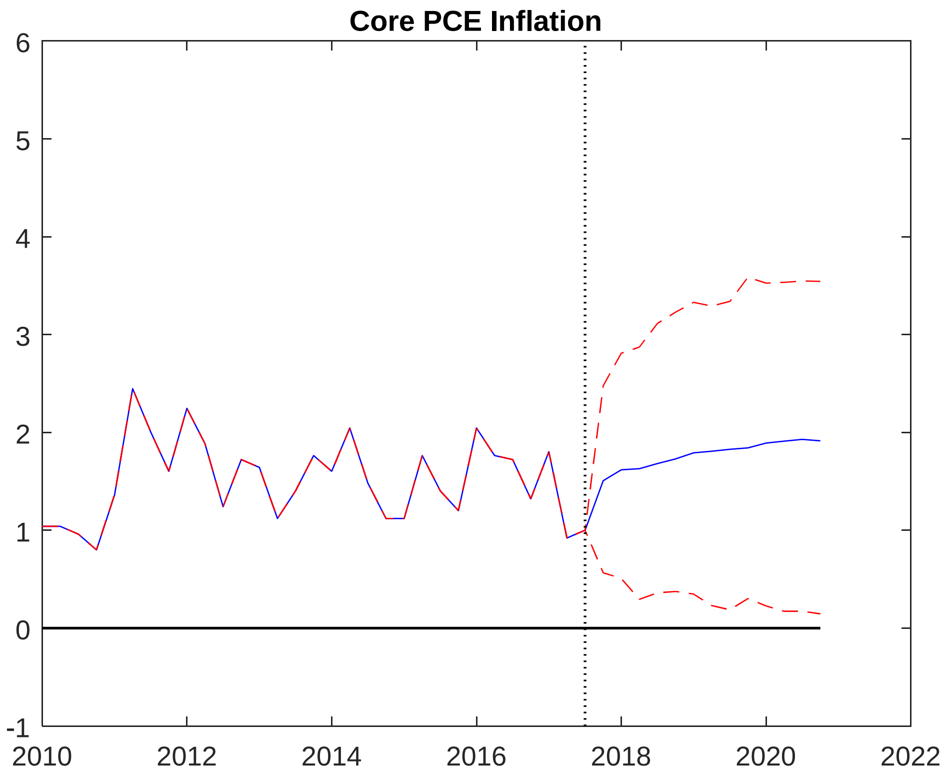

Core PCE Inflation
6
5
4
3
2
1
0
-1
2010
2012
2014
2016
2018
2020
2022

Figure 1c

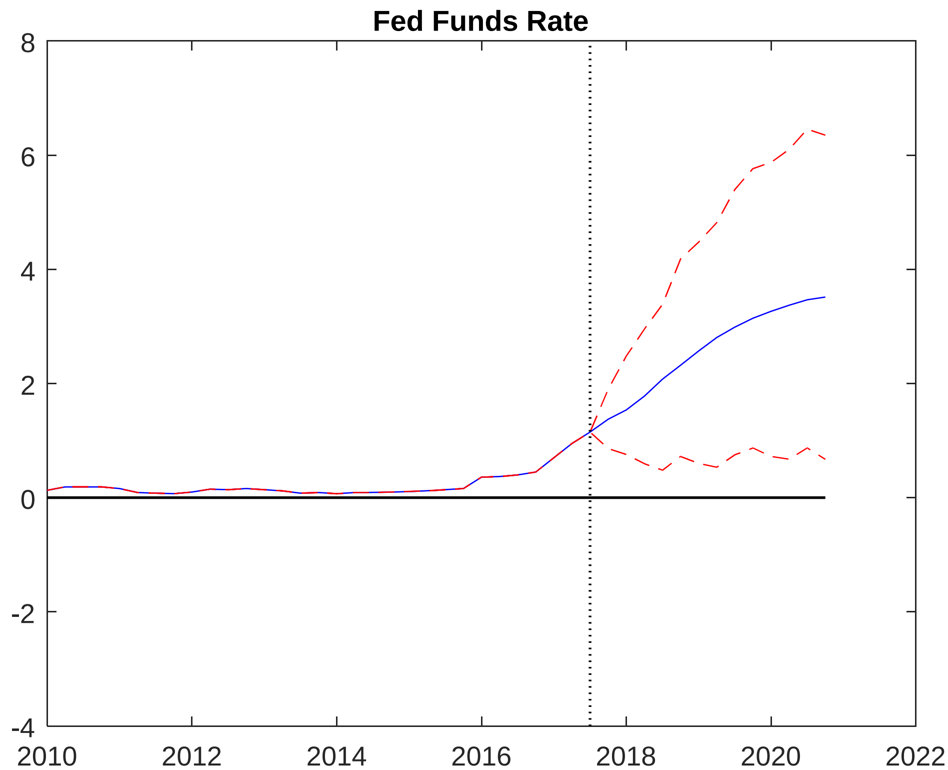
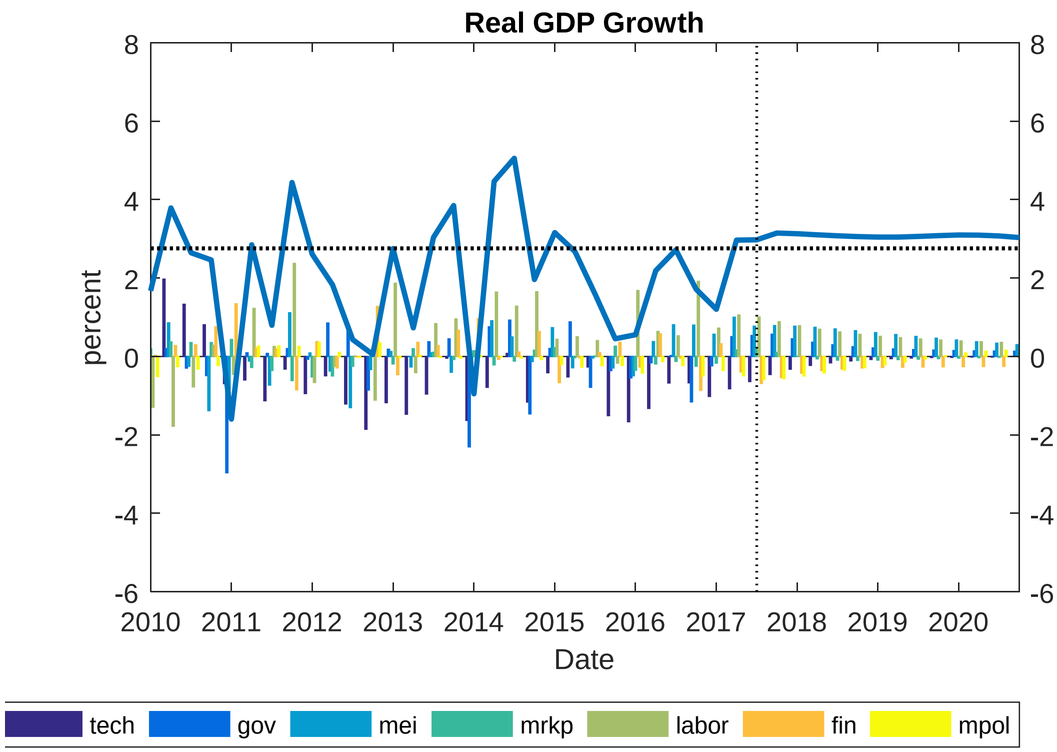


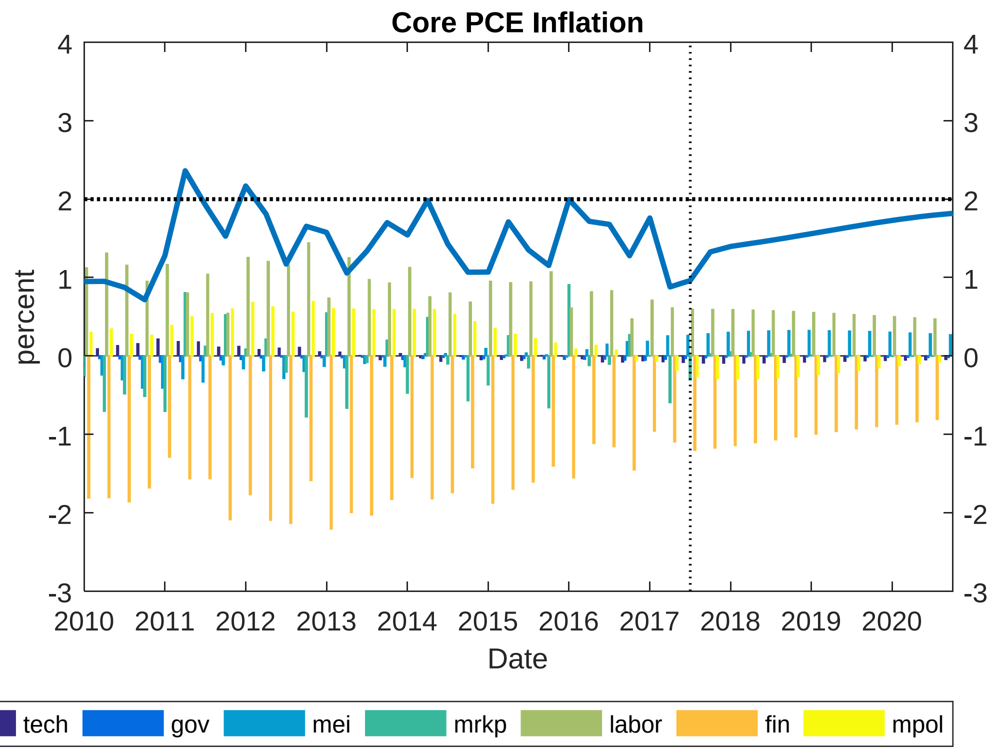
Figure 2a
Shock Decompositions



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

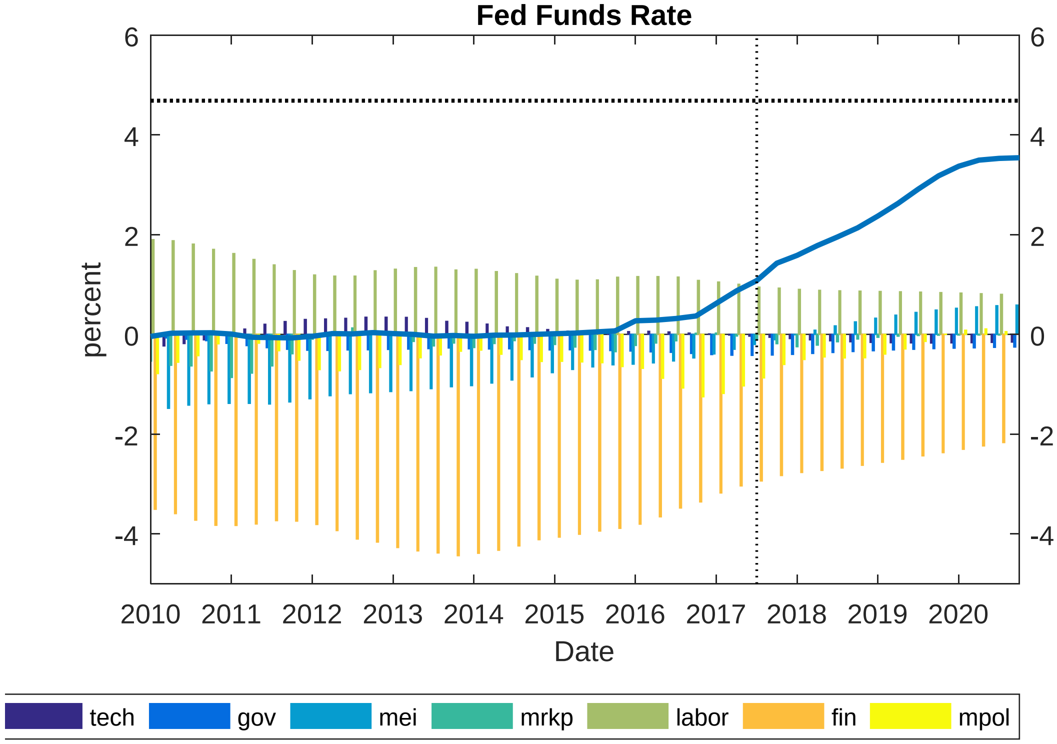
Figure 2b
Shock Decompositions



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

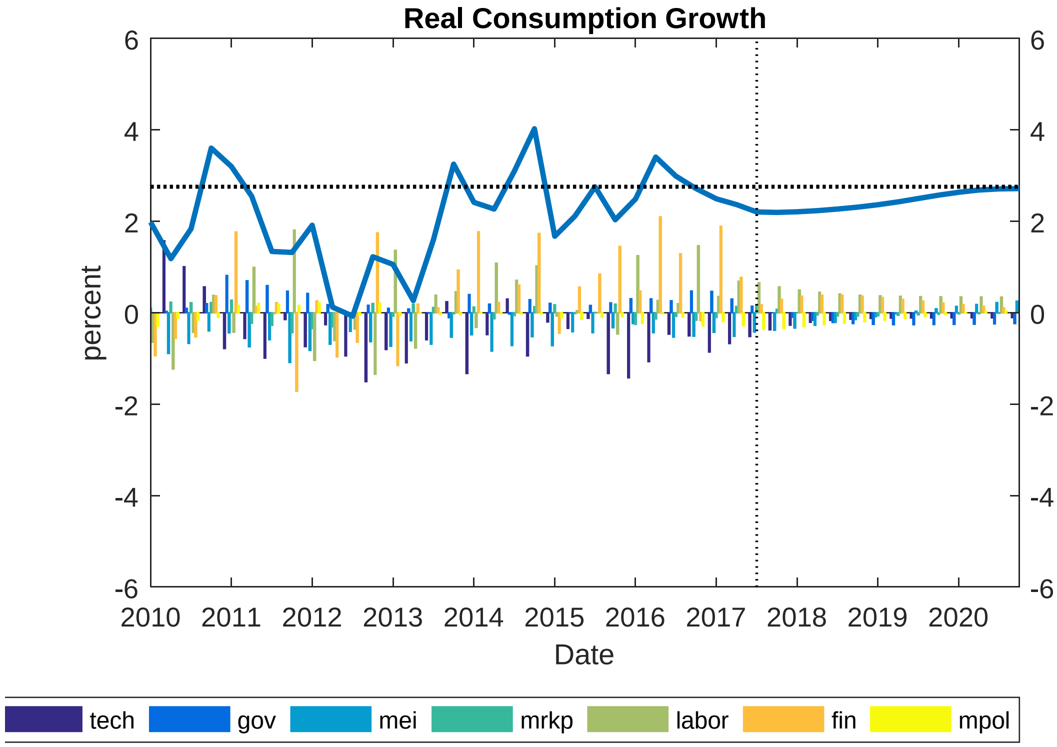
Figure 2c
Shock Decompositions



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

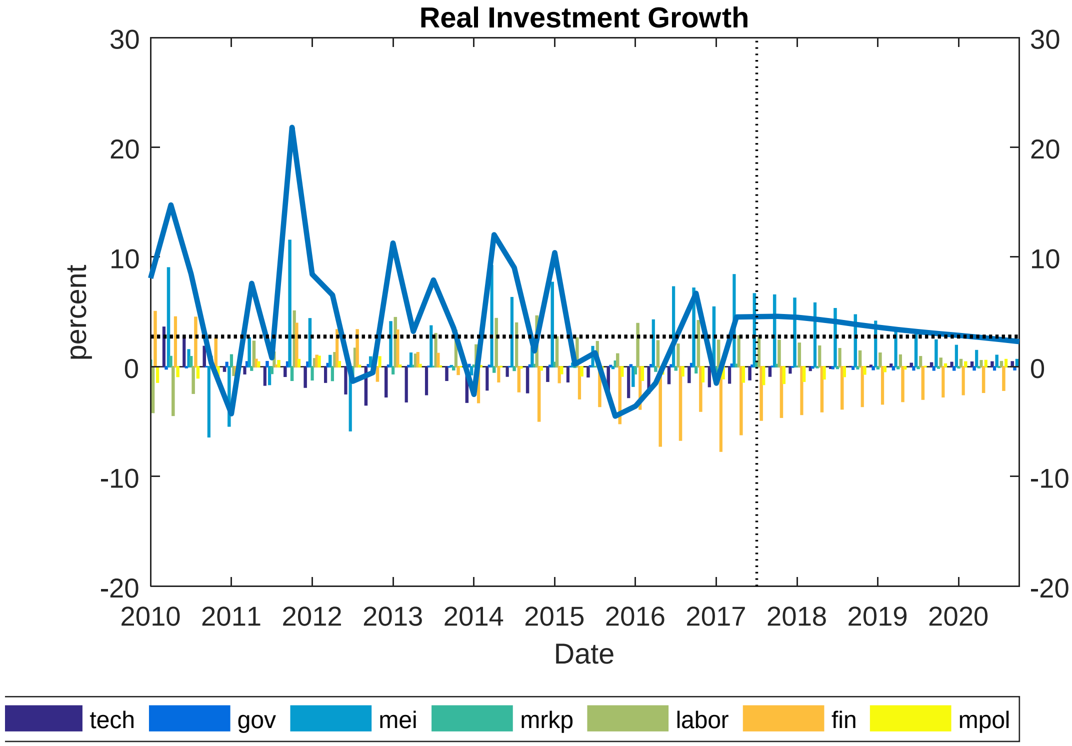
Figure 2d
Shock Decompositions



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

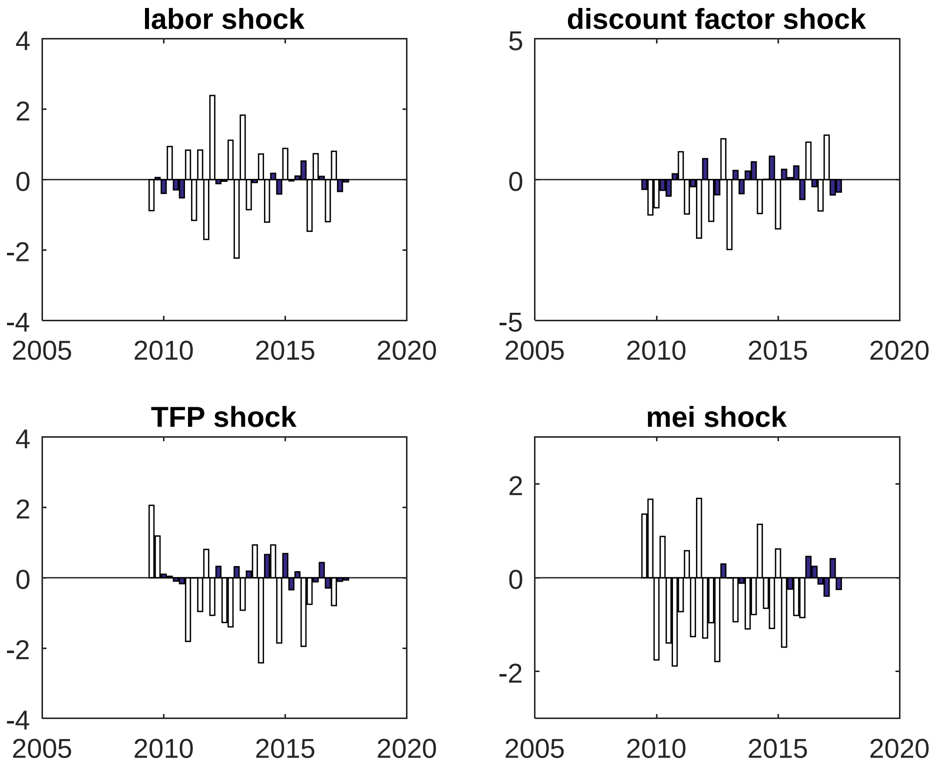
Figure 2e
Shock Decompositions



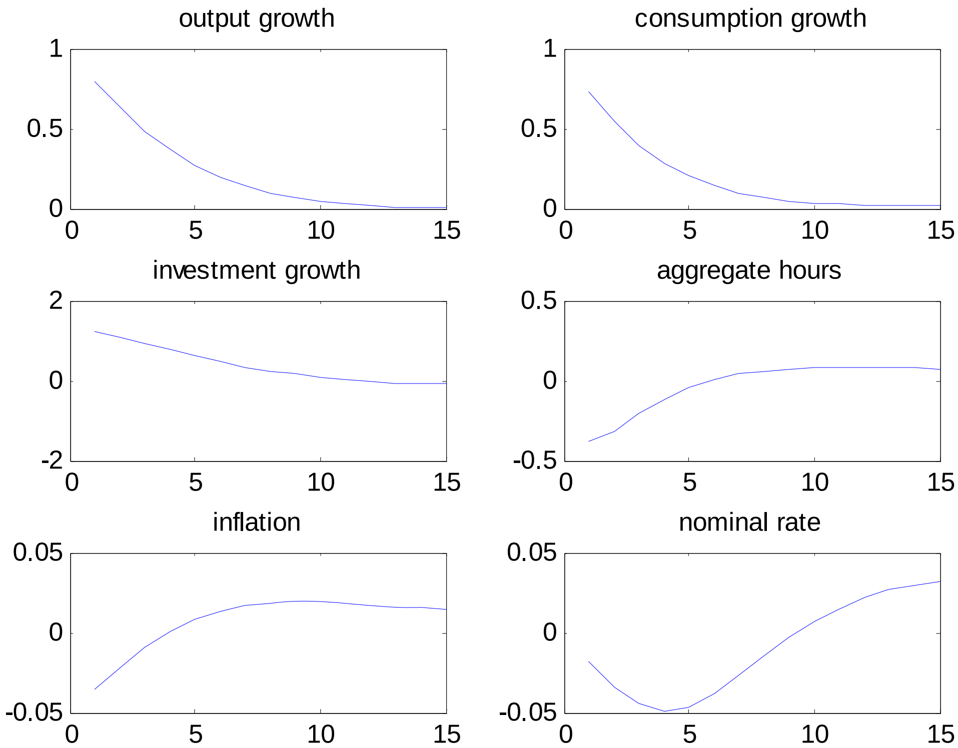
shocks:

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

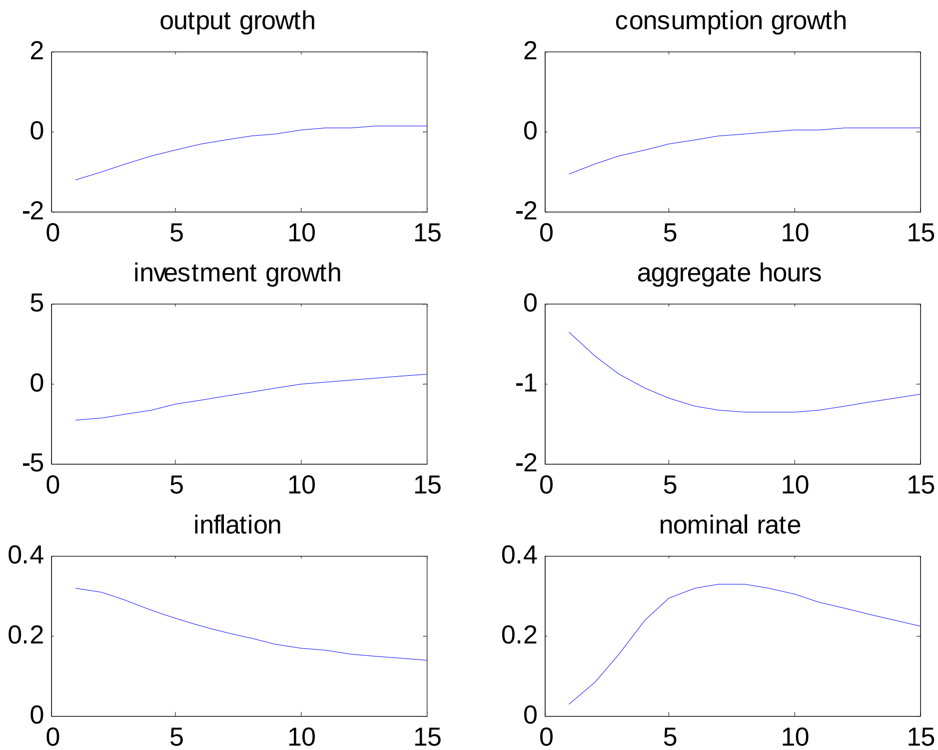
Figure 3
Smoothed Shock Estimates for Conditional Forecast Model
(normalized by standard deviation)



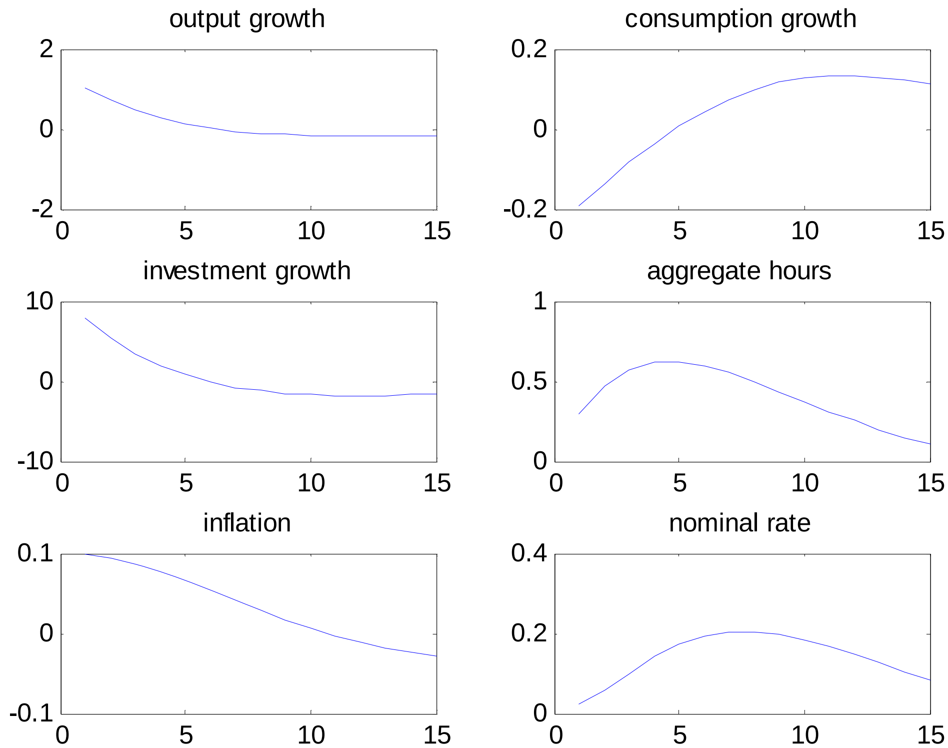
Impulse Responses to TFP shock



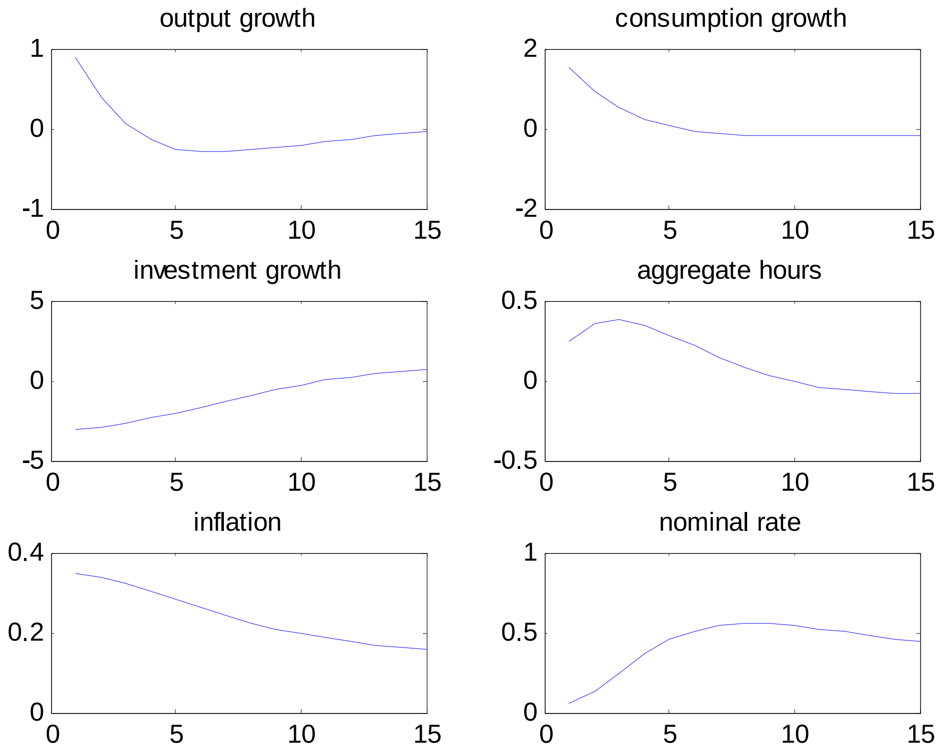
Impulse Response to Leisure Shock



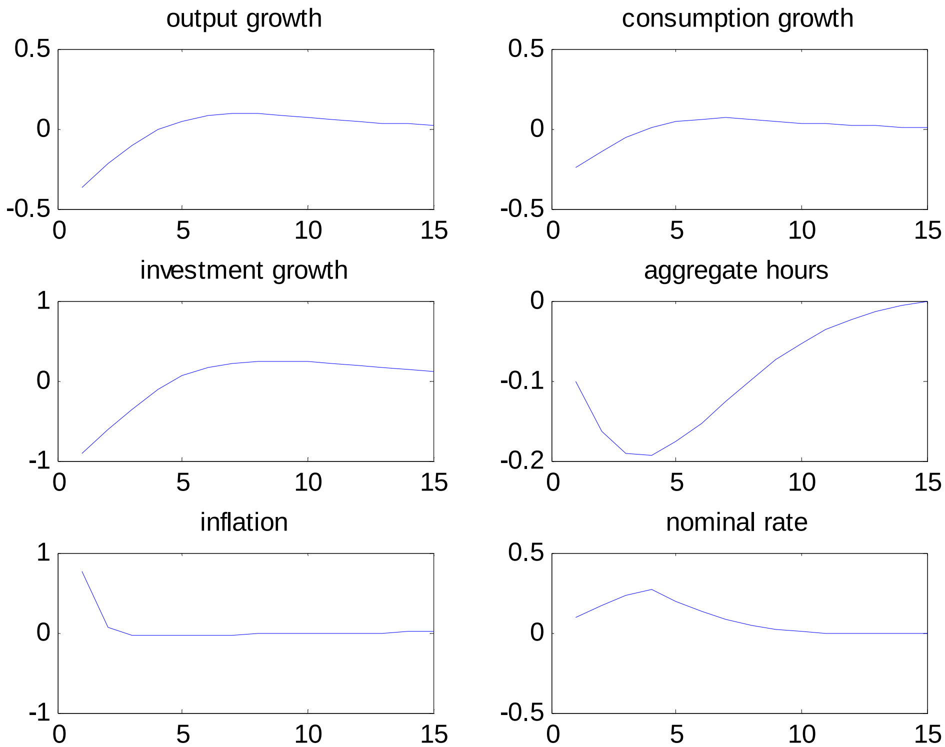
Impulse Responses to MEI Shock



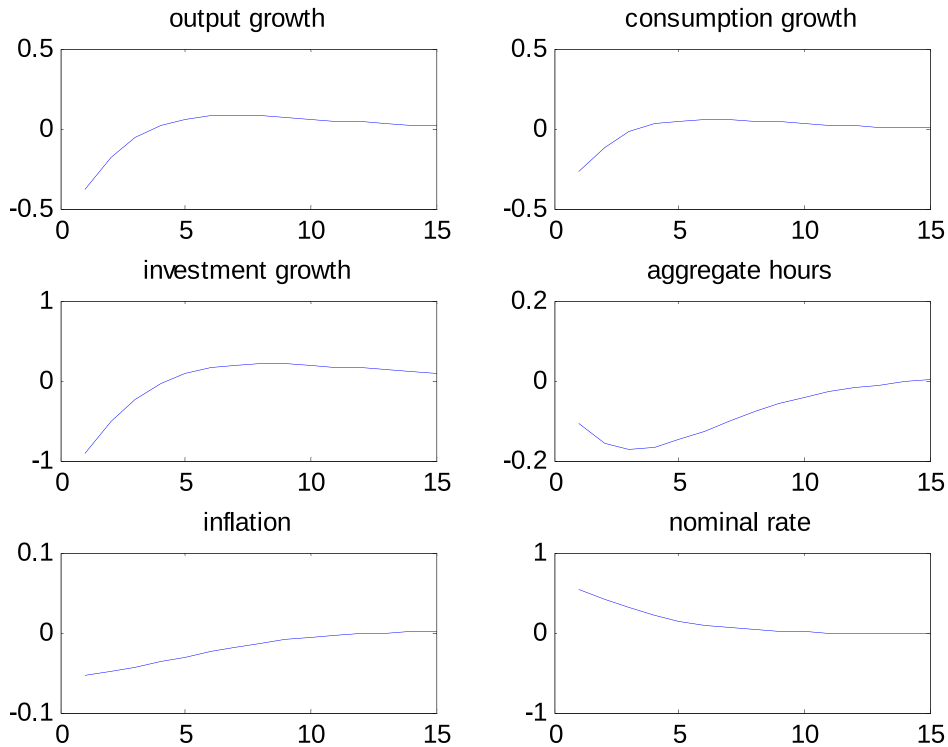
Impulse Responses to Financial Shock



Impulse Responses to Price Markup Shock



Impulse Responses to Unanticipated Monetary Policy Shock



Impulse Responses to Govt Spending Shock