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Date: October 24, 2011
To: Federal Open Market Committee
From: Deborah J. Danker
Subject: DSGE Models Update

The attached memo provides a quarterly update on the projections of the DSGE models that were described at the June FOMC meeting.

System DSGE Project Forecasts¹

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This memo describes the economic forecasts of the four models that are currently part of the System project on dynamic stochastic general equilibrium (DSGE) models. These are the EDO (Board), PRISM (FRB Philadelphia), FRBNY and Chicago models. Although all four models share many common features, as described in the presentation at the June FOMC meeting, they differ in terms of their underlying economic structure, as well as the data used for model estimation.² The structure of the PRISM model is closest to the “canonical” New-Keynesian DSGE model.³ The FRBNY and Chicago models also incorporate a specific financial sector along the lines of Bernanke, Gertler, and Gilchrist (1999).⁴ The Board EDO model has multiple sectors and incorporates exogenous risk premia into the pricing of bonds. Finally, the Chicago model also exploits the information in multiple inflation indicators. This diversity of models is a strength of the project, since each model provides a potentially different perspective on the current state of the economy. It is important to remember that the DSGE models will change over time, as they incorporate developments in research (both in academia and in central banks) and are estimated on additional series.⁵

Forecasts Summary

The current forecasts for real GDP growth, core PCE inflation, and the federal funds rate, as well as those presented at the June FOMC meeting, are displayed in the table and figure at the end of this summary section.⁶ These forecasts treat 2011Q3 estimates for real GDP growth and core PCE inflation as data and project beyond 2011Q3. The projections are also conditional on the anticipation that the federal funds rate will remain near zero through mid-2013, in line with

² See the “System DSGE Project Documentation” memo by Dotsey, Del Negro, Sbordone, and Sill, June 2011.

³ See for example Frank Smets and Rafael Wouters, 2007, “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach,” *American Economic Review*; Marco Del Negro, Frank Schorfheide, Frank Smets and Rafael Wouters, 2007, “On the Fit of New Keynesian Models,” *Journal of Business & Economic Statistics*; Alejandro Justiniano, Giorgio Primiceri and Andrea Tambalotti, 2010, “Investment Shocks and Business Cycles,” *Journal of Monetary Economics*.

⁴ Ben Bernanke, Mark Gertler, and Simon Gilchrist, 1999, “The Financial Accelerator in a Quantitative Business Cycle Framework”, *Handbook of Macroeconomics*.

⁵ Relative to the June memo, for instance, the Chicago model features explicit financial frictions and a time-varying inflation target, as discussed below.

⁶ The table and figure show the mean forecast for real GDP growth and core PCE inflation, and the modal forecasts for the federal funds rate. We choose to report the modal forecast for this latter variable in order to emphasize the zero lower bound. Forecasts for 2014 were not presented in June. A more detailed discussion of the forecasts and in-depth description of the model structure are available in a memo distributed to the Research Directors.

market expectations. A brief description of each model's forecast can be found at the end of the memo.

The growth projections for 2011 (Q4/Q4) are similar across the four models and weaker than those presented in June, as a result of the NIPA revisions and soft recent data. Afterwards, the projected paths of the recovery differ substantially across the models. Three of the models (EDO, FRBNY, and Chicago) do not foresee any significant rebound in economic activity, with Q4/Q4 real GDP growth at or below 3 percent through 2014. For FRBNY and Chicago, in particular, growth remains anemic through the end of the forecast horizon. In these three models the main drivers of the subdued outlook are the same shocks that generated the recession. These shocks, generally associated with frictions in financial intermediation, continue to hinder the return of output to potential. In contrast, the PRISM model sees growth above 4.5 percent in 2012 and 2013. In PRISM the economy is forecast to grow much more rapidly than in the other three models because it projects a strong recovery in the labor market.

None of the models anticipated the strength in inflation in recent quarters, and therefore the 2011 (Q4/Q4) inflation forecasts are higher than they were in June. The models attribute a substantial portion of this increase in inflation to temporary factors, possibly capturing the effect of higher energy prices. As the impact of these factors subsides, all four models project inflation returning to subdued levels, with Q4/Q4 values between 1 and 1.6 percent from 2012 onward. For EDO, FRBNY, and Chicago the subdued inflation results from the weakness in the outlook for real activity. Inflation forecasts are moderate for PRISM as well, in spite of the stronger projections for real activity, since marginal costs remain subdued because of capital deepening.

In terms of interest rates, all four models project a relatively gradual renormalization after the liftoff, with rates in the neighborhood of 2 percent by the end of 2014, consistent with the fact that inflation remains subdued.

Forecast Summary

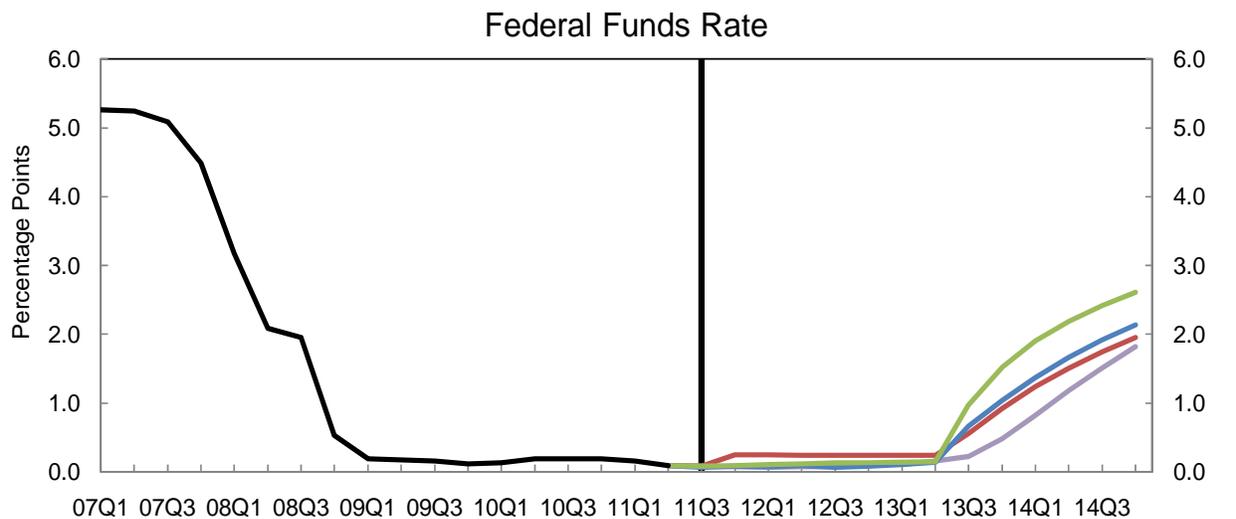
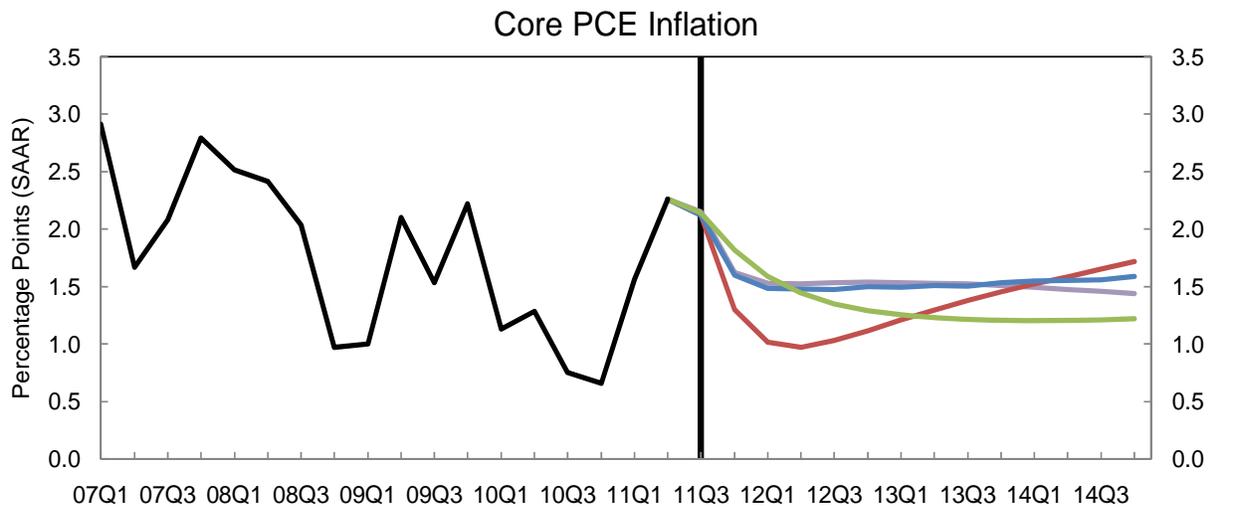
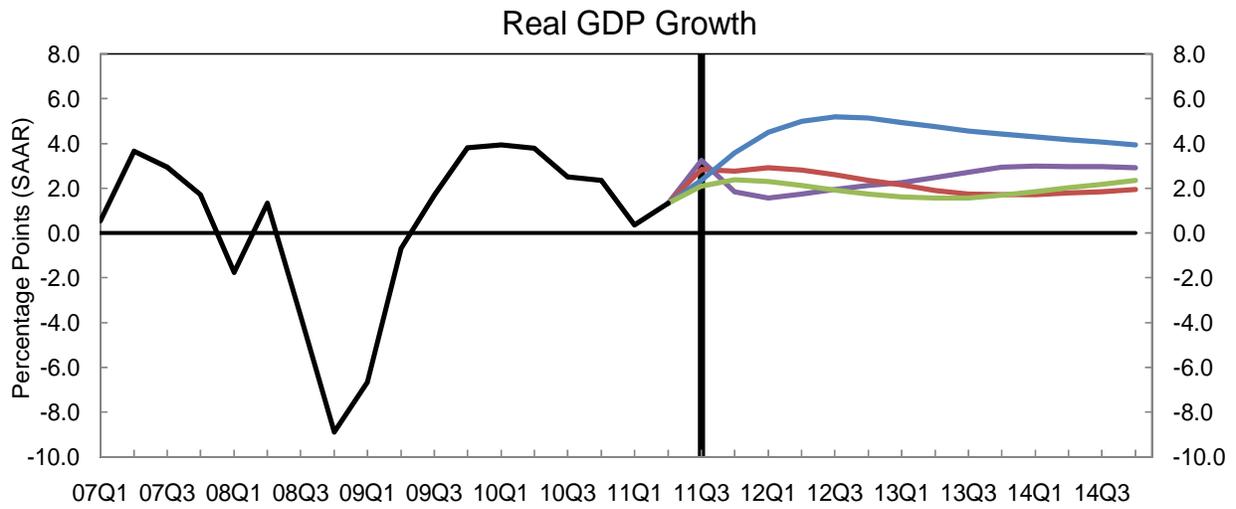
Model	Output Growth (Q4/Q4)							
	2011		2012		2013		2014	
	Nov	June	Nov	June	Nov	June	Nov	June
EDO - Board of Governors	1.7 (0.1,3.4)	2.8 (1.8,3.5)	1.9 (-0.1,3.9)	2.6 (1.1,3.8)	2.6 (0.9,4.5)	2.5 (1.1,3.9)	3.0 (1.3,4.8)	
New York Fed	1.8 (1.1,2.4)	2.1 (0.7,3.2)	2.6 (-0.8,5.0)	2.0 (-1.3,4.6)	1.8 (-1.8,4.8)	1.9 (-1.2,5.2)	1.8 (-1.5,5.1)	
PRISM - Philadelphia Fed	2.0 (1.3,2.8)	3.3 (1.4,6.4)	5.0 (1.4,8.9)	5.1 (0.9,8.7)	4.7 (0.8,9.0)	4.7 (0.1,8.3)	4.2 (0.2,8.4)	
Chicago Fed	1.5 (,,)	3.1 (,,)	2.0 (,,)	4.5 (,,)	1.6 (,,)	4.4 (,,)	2.1 (,,)	
Median Forecast*	1.8	2.9	2.3	3.5	2.2	3.4	2.5	

Model	Inflation (Q4/Q4)							
	2011		2012		2013		2014	
	Nov	June	Nov	June	Nov	June	Nov	June
EDO - Board of Governors	1.9 (1.7,2.1)	1.5 (1.3,1.7)	1.4 (0.8,2.1)	1.4 (0.8,1.9)	1.4 (0.7,2.1)	1.4 (0.8,2.0)	1.4 (0.7,2.1)	
New York Fed	1.8 (1.6,2.0)	1.4 (1.0,1.7)	1.0 (0.3,1.7)	1.1 (0.3,1.8)	1.3 (0.4,2.0)	1.5 (0.6,2.3)	1.6 (0.7,2.4)	
PRISM - Philadelphia Fed	1.9 (1.6,2.1)	1.3 (0.4,2.1)	1.5 (0.2,2.8)	1.1 (-0.3,2.7)	1.5 (0.0,3.1)	1.3 (-0.2,3.0)	1.6 (0.0,3.1)	
Chicago Fed	1.9 (,,)	1.4 (,,)	1.4 (,,)	0.6 (,,)	1.2 (,,)	0.3 (,,)	1.2 (,,)	
Median Forecast*	1.9	1.4	1.4	1.1	1.4	1.3	1.5	

Model	Federal Funds Rate (Q4)							
	2011		2012		2013		2014	
	Nov	June	Nov	June	Nov	June	Nov	June
EDO - Board of Governors	0.1 (0.0,0.7)	0.4 (0.2,1.4)	0.1 (0.0,1.9)	1.6 (0.6,2.9)	0.5 (0.0,2.3)	2.4 (1.1,3.8)	1.8 (0.6,3.6)	
New York Fed	0.3 (0.3,0.8)	0.3 (0.3,1.1)	0.2 (0.3,1.4)	0.9 (0.3,2.1)	0.9 (0.3,2.3)	1.8 (0.5,3.3)	1.9 (0.6,3.5)	
PRISM - Philadelphia Fed	0.1 (-0.4,0.7)	0.2 (0.0,1.2)	0.1 (-1.5,1.9)	0.6 (0.0,2.4)	1.0 (-1.4,3.2)	1.4 (0.0,3.9)	2.1 (-0.2,5.0)	
Chicago Fed	0.1 (,,)	0.1 (,,)	0.1 (,,)	1.0 (,,)	1.5 (,,)	2.6 (,,)	2.6 (,,)	
Median Forecast*	0.1	0.2	0.1	0.9	1.0	2.1	2.0	

For each individual forecast, the numbers in parentheses represent 68% probability bands.

* The median forecast is calculated as the median of the Q4/Q4 projections from the forecasters.



— EDO — New York — PRISM — Chicago

Detailed Model Forecasts

The EDO model

The EDO model projects that real GDP will advance at a pace modestly above trend going forward -- about $2\frac{3}{4}$ percent, on average, over 2012-2014. This slightly above-trend pace of growth is accompanied by an inflation forecast of about $1\frac{1}{2}$ percent per year, below the target of 2 percent. The subdued inflation forecast reflects the labor market slack apparent in the shortfall of output relative to its estimated long-run trend. The model attributes most of the recent increase in core inflation to mark-up shocks, which capture transitory movements in inflation and have very little estimated persistence. Consequently, these shocks have a limited effect on inflation projections beyond 2011.

The projected recovery remains strongly influenced by the unwinding of the adverse shocks to financial conditions in 2008 and early 2009. With the waning of these shocks, households restrain consumption while increasing labor supply in order to rebuild wealth. These efforts would typically produce a fairly strong recovery, but have been offset by weak productivity growth, a binding lower bound constraint on monetary policy accommodation, and the lingering effect of economy-wide risk premium shocks, which capture strains in financial intermediation.

The impact of these last two factors is intensified by conditioning the forecast on a policy rate lift off that takes place in 2013Q3, substantially later than would be estimated from the model's usual information set. The model interprets the low expected path of the interest rates through mid-2013 as an endogenous response of policy to continued strains in financial conditions going forward. Indeed, the economy-wide risk premium remains at its current level for the first two years of the projection instead of gradually falling as its pre-crisis dynamics would have implied. The low expected path of the interest rates also reflects a more accommodative stance of monetary policy over the projection, essentially offsetting the impact on real activity and inflation of higher risk-premiums. The federal funds rate gradually rises after 2013Q3 to reach $1\frac{3}{4}$ percent by the end of 2014.

The FRBNY Model

The FRBNY model forecast is obtained using data released through 2011Q2, augmented for 2011Q3 with observations on the federal funds rate and the spread between Baa corporate bonds and 10-year Treasury yields, and the NY Fed staff forecast for real GDP growth, core PCE inflation and hours.

The model projects weak growth in economic activity, as it did in June. The projection for output growth in 2011 (Q4/Q4) is 1.8 percent, not too different from the June projection of 2.1 percent. Growth picks up in 2012 (Q4/Q4) to 2.6 percent, and returns to roughly 2 percent in 2013-2014. Inflation is 1.8 percent in 2011 (Q4/Q4), higher than in the June projections, due to the recent strong readings for core PCE inflation. In spite of this, inflation forecasts from 2012 onwards are actually lower than in June, due to the projected weakness in economic activity. In fact, real marginal costs, which are the key determinant of the evolution of inflation in the model, are currently roughly 3 percent below the historical mean and projected to remain below average through the end of the forecast horizon.

There is significant uncertainty around the real GDP forecasts, and the risk of a recession is far from negligible: the chance of negative readings for growth is larger than 20 percent in any given quarter. As far as inflation is concerned, for both 2012 and 2013 the 68 percent probability bands for Q4/Q4 inflation are within the 0-2 percent interval, implying that the model places great probability on inflation realizations below the implicit FOMC target at least through 2013.

The main drivers of the subdued real GDP and inflation outlook are the same forces that were responsible for the Great Recession, namely the two shocks associated with the financial system: spread and MEI (marginal efficiency of investment) shocks. Spread shocks raise credit spreads, hence the cost of capital, hindering the entrepreneurs' ability to channel resources to the productive sector. MEI shocks directly affect the technological ability of entrepreneurs to transform investment goods into productive capital. They capture financial headwinds that are not reflected in the spread, and have a negative impact on economic activity. The impact of these shocks on the level of output is very long-lasting, implying that output is below trend throughout the forecast horizon. In turn, the fact that economic activity is well below trend pushes down

inflation and consequently interest rates (given the Fed's estimated reaction function). Shifts in the trend growth of productivity (and hence in the trend of potential output) play only a minor role in the FRBNY forecasts. The model attributes the pickup in core inflation in 2011 to mark-up shocks. These shocks push inflation above marginal costs, and capture swings in inflation such as those due to oil price fluctuations. Their estimated impact on inflation is however only transitory, so that they have almost no effect on the inflation forecasts for the subsequent periods.

Finally, imposing near-zero expectations for the federal funds rate through mid-2013 has only a modest impact on the forecasts for output and inflation. The model does not view the federal funds rate at the zero lower bound as deviating significantly from the estimated policy rule, at least through the end of 2012. After this, however, the federal funds rate in 2013 and 2014 is forecast to be about 75bp lower than implied by the historical rule. Note that this policy accommodation is not sufficient to bring economic activity back to trend, at least through the end of the forecast horizon.

The PRISM Model

The Philadelphia Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2011Q2 that are then supplemented with 2011Q3 projections of output, consumption, investment, wages, and hours worked from the most recent Macroeconomic Advisors forecast, (which forecasts 2011Q3 real GDP growth of about 2.4 percent).

PRISM continues to forecast a fairly strong recovery with real GDP growth at about 5 percent (Q4/Q4) in 2012 and 2013, falling to about 4.2 percent in 2014. While output growth is projected to be fairly robust, inflation remains contained at about 1.5 percent through the forecast horizon. By the end of 2013Q4, the funds rate is projected to increase to about 1 percent. By the end of 2014, the funds rate stands at a bit over 2 percent.

According to PRISM, negative TFP, marginal efficiency of investment (MEI), and labor market shocks have been key factors accounting for below-trend real output growth in 2011. The uptick in core PCE inflation in 2011 is largely driven by temporary factors, captured by mark-up shocks, and to some extent by accommodative monetary policy. Going forward, the model

predicts a decline in core PCE inflation. The rise in real output growth in 2012 and 2103 is driven by consumption growth, which is projected to be a bit above 4 percent over the next three years, and to a less extent by investment growth, which is expected to run at an above-trend pace.

Shocks that capture frictions in the labor market play an important role in explaining the recent recession. The model expects the impact of these shocks to wane considerably over the forecast horizon, and consequently projects a strong rebound in the labor market. This rebound in aggregate hours lies behind PRISM's strong growth forecasts for output, and at the same time puts upward pressure on inflation. Such pressure is offset by changes in the savings behavior of households, which the model captures via exogenous changes in the household's discount factor. An increase in the discount factor – a shift in preferences toward future consumption -- leads in this model to lower consumption, increased savings, and higher investment. The ensuing capital deepening lowers marginal costs and therefore helps to keep inflation in check.

Conditioning on the policy rate remaining at the zero lower bound through 2013 has a significant impact on the forecasts. Were the federal funds rate expectations not used as conditioning information for the forecast, PRISM would project a significantly stronger path for core inflation, a moderately stronger path for real output growth, and consequently a much more aggressive monetary policy tightening over the next 3 years. This is because the model captures the exceptionally low expectations for the nominal rate via discount factor shocks that induce a lower expected path for the real rate. As explained above, absent these shocks, the inflation projections would be higher.

The Chicago model

The Chicago Fed model has undergone two significant changes since the June FOMC meeting. First, the model now incorporates a financial accelerator mechanism, as in Bernanke, Gertler and Gilchrist (1999). Observations of private balance sheets and interest rate spreads inform this mechanism. Second, the Taylor rule's intercept is allowed to slowly drift. This intercept shift is referred to as the *inflation drift* shock, as it dominates changes in long-run expected inflation. This drift is disciplined by equating model-based average expected consumer price inflation over the next 40 quarters with ten-year ahead core CPI forecasts derived from a

reduced form affine term structure model. The use of long-term inflation expectations shapes the model's forecast for inflation by anchoring a time varying end-point. Expected core CPI inflation is currently at roughly 1.75 percent, well below the model's 2.5 percent steady state level.⁷

Regarding the first modification, introducing the financial accelerator allows the model to account for the influence of private balance sheets in macroeconomic performance. In this way, fluctuations in the external finance premium, private net worth and the state of the economy as well as the policy stance are explicitly linked. To complement this change, the model now has two financial disturbances. The spread shock generates fluctuations in the external finance premium beyond the level warranted by current economic conditions, and the net worth shock generates exogenous fluctuations in private balance sheets.

To identify parameters governing the financial accelerator the set of observables for estimation is modified by including data on borrowing, and by changing the measure of spreads. Nonfinancial borrowing is measured as the log first difference of the ratio of private credit to nominal GDP.⁸ The High Yield/AAA corporate bond spread is replaced with a broader measure that includes spreads on Asset backed securities.

The Chicago model forecasts a return of real GDP growth to near trend, estimated at roughly 2.6 percent, in the fourth quarter of 2011, with 2011 Q4/Q4 growth at 1.5 percent. The near-term outlook is characterized by slightly above-trend growth in investment, and a very slight increase in nondurables and services consumption growth by the end of the year. Going forward, the model forecasts investment growth to continue near its trend until increasing in late 2013, while consumption growth is projected to steadily decline over this period. This leads to an expected path for Q4/Q4 real GDP growth that peaks at 2 percent in 2012 and then drops to 1.6 percent in 2013 before rebounding to 2.1 percent in 2014. Consistent with the projections for real activity, the outlook for hours is muted, suggesting protracted weakness in the labor market.

Furthermore, with resource slack remaining elevated, the model projects core PCE inflation to

⁷Until recently, inflation expectations had recovered from their relatively low readings through early 2011. In the last two quarters however, the measure of expected long-term inflation has edged down. The model interprets this development as negative realizations of the inflation drift shock.

⁸The numerator sums two components: Nonfinancial Business and Household Credit Market Debt Outstanding, each taken from the Flow of Funds accounts. The inclusion of non-corporate and household credit market debt in the measure of nonfinancial borrowing is consistent with the model's definition of investment, which includes consumer durables and residential investment in addition to business fixed investment.

steadily decline from a peak of 2.1 percent in 2011Q3 to 1.4 percent in 2012 (Q4/Q4) and 1.2 percent in 2013 (Q4/Q4).

The model interprets the history of output, consumption, investment, and hours over the last four quarters as stemming primarily from adverse demand shocks which reduce output and inflation. In particular, positive shocks to the households' discount factor are primarily responsible for the recent weakness in consumption growth. These disturbances depress household spending, output and hours, as well as inflation. Furthermore, adverse spread and private net worth shocks account for the muted growth of investment. Both of these negative disturbances also drag down output, hours, and inflation. Meanwhile, a shock capturing fluctuations in net exports, government spending and changes in the valuations of inventories further depressed output, hours, and prices, particularly at the beginning of the year, while slightly boosting consumption. The combined effect of these demand disturbances has been to lower four quarter GDP growth and core PCE inflation as of 2011Q3 by almost 1 and 0.2 percent, respectively.

On the supply side, over the last four quarters positive shocks to wage and price markups pushed annual core PCE inflation higher by roughly half percent. Meanwhile, adverse shocks to neutral technology have also somewhat boosted inflation, as well as hours, while contributing negatively to output, consumption and investment growth since 2010Q3. All of these contractionary forces have been partially offset by monetary policy signals, which in our model capture the effects of forward guidance regarding the path of the federal funds rate over the next seven quarters. According to the model, forward guidance added about 2 percent to four quarter output growth from 2010Q3 through 2011Q3, and roughly 0.6 percent to core PCE inflation over the same time period. Policy signals supported consumption and investment growth, as well as hours. Spread and net worth shocks have particularly persistent effects on economic activity, so their recent realizations strongly influence the forecast. Nevertheless, the forward guidance in place moderates their impact on investment and prevents a steeper decline in consumption growth.