BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

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To: Federal Open Market Committee

From: Brian F. Madigan

Subject: DSGE Models Update

The attached memo provides an update on the projections of the DSGE models.

System DSGE Project Forecasts

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This memo describes the economic forecasts of the three models that are currently part of the System project on dynamic stochastic general equilibrium (DSGE) models. These are the EDO (Board), PRISM (FRB Philadelphia), and FRBNY models. We first give a summary of the model forecasts and then describe each model's forecasts in greater detail.

Summary of Model Forecasts

The current forecasts for real GDP growth, core PCE inflation, and the federal funds rate are displayed in the table and figures at the end of this summary section. These forecasts were obtained using actual data through 2016Q1 and conditioning assumptions or 'nowcasts' for 2016Q2, where the sources of the nowcast vary slightly across the models (EDO, the FRBNY model, and PRISM use forecasts from the Board staff, the FRBNY staff and Macroeconomic Advisers, respectively). For all the models the federal funds rate path is determined by the respective estimated policy reaction function, and is no longer constrained to be consistent with market expectations. For the sake of comparison, the tables include the April Tealbook forecast (the most recent Tealbook forecast available to us), as well as the DSGE model forecasts prepared for the March FOMC meeting. The memo also presents model-based estimates and forecasts of the real natural rate of interest, defined in each model as the equilibrium real rate of interest that would prevail in the absence of sluggish adjustment of nominal prices and wages. In addition, the memo reports estimates and forecasts of model-based output gaps. These are computed as percent deviation of actual output from the natural level of output, the latter again defined as the real level of output that would prevail if prices and wages were fully flexible.

GDP growth forecasts for 2016 are between 1.6 and 2.1 percent, a narrower and lower range compared to that reported in March (1.8 to 2.6 percent). Over the entire forecast horizon, the models individually predict the pace of GDP growth to pick up: the median projection calls for 2.1 percent growth in 2016, 2.3 percent in 2017, and 2.6 percent in 2018. Compared to the March median, growth over the forecast horizon is now projected to be about 0.2 percentage points in 2016 and the same in 2017 and 2018. While all the models show a downward revision to 2016 output growth, only PRISM pared back its forecast for 2017 and 2018. Even so, PRISM continues to show the most optimistic forecast with growth at a 3 percent or higher pace in 2017 and 2018. EDO and FRBNY forecast growth at 2.3 and 2.2 percent, respectively, in 2017, rising to 2.6 and 2.5 percent, respectively, in 2018. The median DSGE model forecast is similar to the April Tealbook in 2016 and 2017, and stronger in 2018 when the Tealbook projects that growth decelerates to 2 percent.

Turning to the inflation projections, the median of the DSGE models' core inflation forecast is 1.9 percent for 2016, up from 1.7 percent in the March projection and 0.4 percentage points higher than the April Tealbook projection. That reflects an increase in PRISM's and FRBNY's projections relative to March. For the remainder of the forecast horizon, the DSGE median forecast is slightly higher than March (2.0 versus 1.8 percent in 2017 and 2.1 versus 2.0 percent in 2018) as upward revisions of PRISM dominate essentially unchanged projections for EDO and FRBNY. Overall, these inflation forecasts remain stronger than the April Tealbook, which has core inflation at 1.6 percent in 2017 and 1.8 percent in 2018. As it has been for some time, the FRBNY forecasts for inflation remain the weakest (1.2 percent in 2017 and 1.3 percent in 2018) consistent with the model's projection of modest output growth and sizeable output gaps.

The broad story behind the forecasts is similar across the different models. The models generally agree on the reason why output gaps are still open: past shocks to financial conditions – so-called headwinds – have a lasting effect on the economy and continue to restrain aggregate demand and, in particular, investment. Negative productivity shocks have also held down the level of economic activity. The restraint due to past financial conditions has broadly lessened over the past two years, as evidenced by the rise in the estimated real natural rate of interest from very negative territory to zero or higher in the current quarter. Over time, these headwinds will continue to abate and the estimated natural rate in all the models is projected to rise to a range of 0.7 to 1.4 percent by the end of 2018.

The models estimate the current output gap at near -1.6 percent, about 0.5 percentage point lower than the April Tealbook. The speed at which the gap is projected to close over the next three years varies across models. EDO has the gap at -1.5 percent by 2016Q4, compared to the more gradual pace for PRISM and FRBNY (-1.8 percent in both). By 2018Q4, EDO has the gap narrowing slightly to -1.2 percent, compared to PRISM at -1.5 percent, and FRBNY at -1.9

percent. FRBNY's projections remain the most pessimistic, attributing to the recent turbulence in financial markets and the associated widening of credit spreads a further delay in the return of output to potential and inflation to mandate consistent levels. The April Tealbook output gap projection is much more optimistic than the DSGE models, with a positive gap of 0.5 percentage points in 2016Q4, rising to 1.6 percent in 2018Q4.

The expected speed of renormalization in the federal funds rate varies across models, consistent with their different assessments of the speed at which economic activity and inflation rebound. PRISM and FRBNY show little change in the pace of renormalization compared to March, while EDO has shifted down the path of the funds rate significantly. EDO has the funds rate at 1.2 percent in 2016Q4 (vs. 1.9 percent in March), 2.4 percent in 2017Q4 (vs. 2.9 percent in March), and 3.2 percent in 2018Q4 (vs. 3.5 percent in March). The lower federal funds rate path is accounted for by a lower initial condition on the funds rate and downward adjustments to inflation and the output gap in the first half of 2016. PRISM continues to have the most rapid renormalization with the funds rate reaching 1.6 percent in 2016Q4, 3 percent in 2017Q4, and 3.6 percent in 2018Q4. Consistent with its weaker near-term output forecast, FRBNY has a more gradual pace of normalization with the funds rate at 1.4 percent in 2017Q4 and 2.2 percent in 2018Q4. The April Tealbook forecast for the funds rate is within the range of the DSGE model forecasts at 2.4 percent in 2017 and 3.3 percent in 2018.

Forecasts

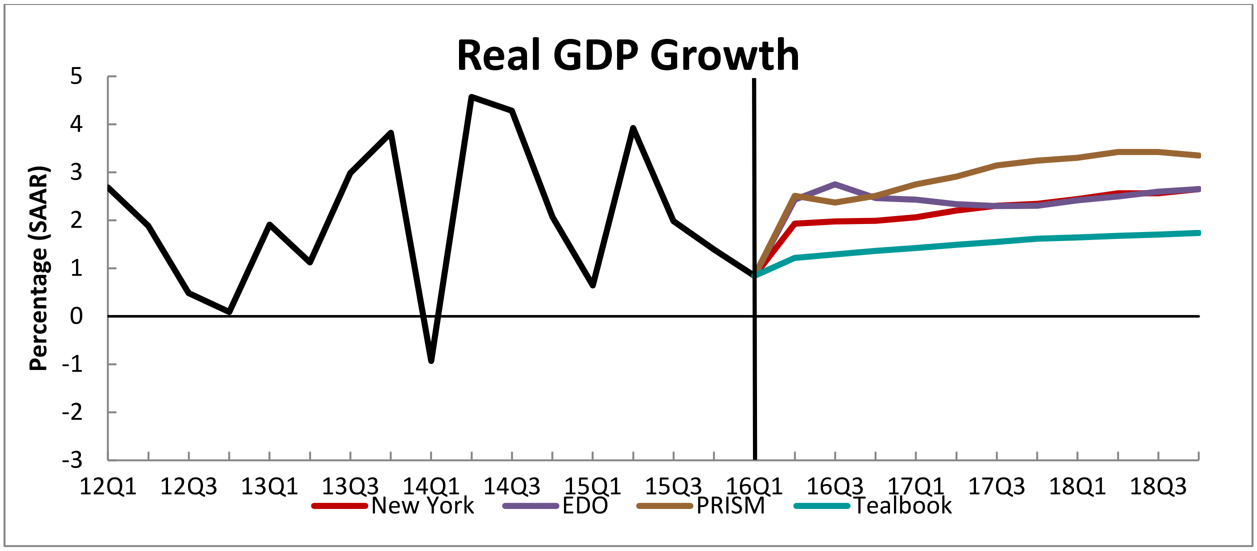
Model	Output Growth (Q4/Q4) 2016		2017		2018	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**2.1** **(1.0,3.2)**	2.3 (0.8,3.8)	**2.3** **(0.3,4.4)**	2.3 (0.2,4.3)	**2.6** **(0.4,4.7)**	2.6 (0.4,4.7)
New York Fed	**1.6** **(0.0,2.8)**	1.8 (-0.5,3.2)	**2.2** **(-0.9,4.6)**	2.2 (-0.7,4.5)	**2.5** **(-0.3,5.2)**	2.4 (-0.3,5.0)
PRISM - Philadelphia Fed	**2.1** **(0.6,3.5)**	2.6 (0.4,4.9)	**3.0** **(-0.2,6.6)**	3.3 (0.0,6.9)	**3.4** **(-0.1,7.1)**	3.5 (0.0,7.2)
Median Forecast*	**2.1**	2.3	**2.3**	2.3	**2.6**	2.6
April Tealbook	**2.0**		**2.4**		**2.0**	

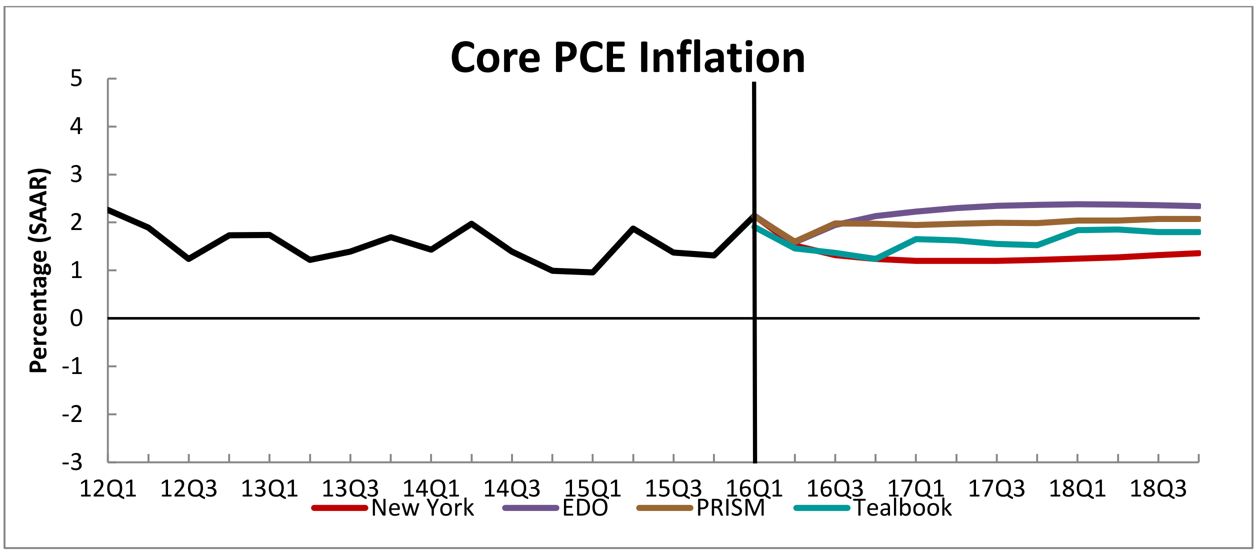
Model	Core PCE Inflation (Q4/Q4) 2016		2017		2018	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**2.0** **(1.6,2.3)**	2.1 (1.7,2.6)	**2.3** **(1.5,3.1)**	2.4 (1.6,3.3)	**2.4** **(1.4,3.3)**	2.4 (1.4,3.3)
New York Fed	**1.6** **(1.2,1.9)**	1.3 (0.8,1.8)	**1.2** **(0.3,2.1)**	1.2 (0.3,1.9)	**1.3** **(0.2,2.4)**	1.3 (0.4,2.1)
PRISM - Philadelphia Fed	**1.9** **(1.4,2.4)**	1.7 (0.8,2.6)	**2.0** **(0.5,3.5)**	1.8 (0.4,3.5)	**2.1** **(0.4,3.8)**	2.0 (0.2,3.6)
Median Forecast*	**1.9**	1.7	**2.0**	1.8	**2.1**	2.0
April Tealbook	**1.5**		**1.6**		**1.8**	

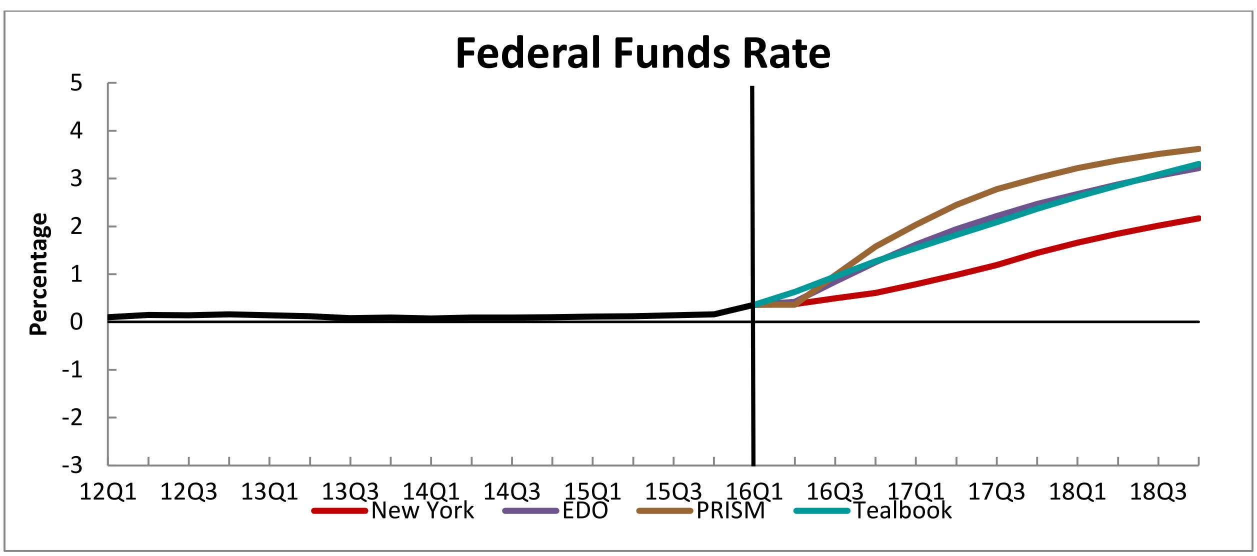
Model	Federal Funds Rate (Q4) 2016		2017		2018	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**1.2** **(0.5,2.1)**	1.9 (0.9,2.9)	**2.4** **(1.0,4.0)**	2.9 (1.3,4.5)	**3.2** **(1.3,5.1)**	3.5 (1.5,5.4)
New York Fed	**0.6** **(0.1,1.7)**	0.7 (0.1,2.1)	**1.4** **(0.3,3.1)**	1.4 (0.2,3.4)	**2.2** **(0.6,4.1)**	2.1 (0.5,4.2)
PRISM - Philadelphia Fed	**1.6** **(0.7,2.5)**	1.6 (0.3,2.8)	**3.0** **(1.2,5.1)**	2.9 (0.5,5.0)	**3.6** **(0.8,6.1)**	3.5 (0.7,6.3)
Median Forecast*	**1.2**	1.6	**2.4**	2.9	**3.2**	3.5
April Tealbook	**1.3**		**2.4**		**3.3**	

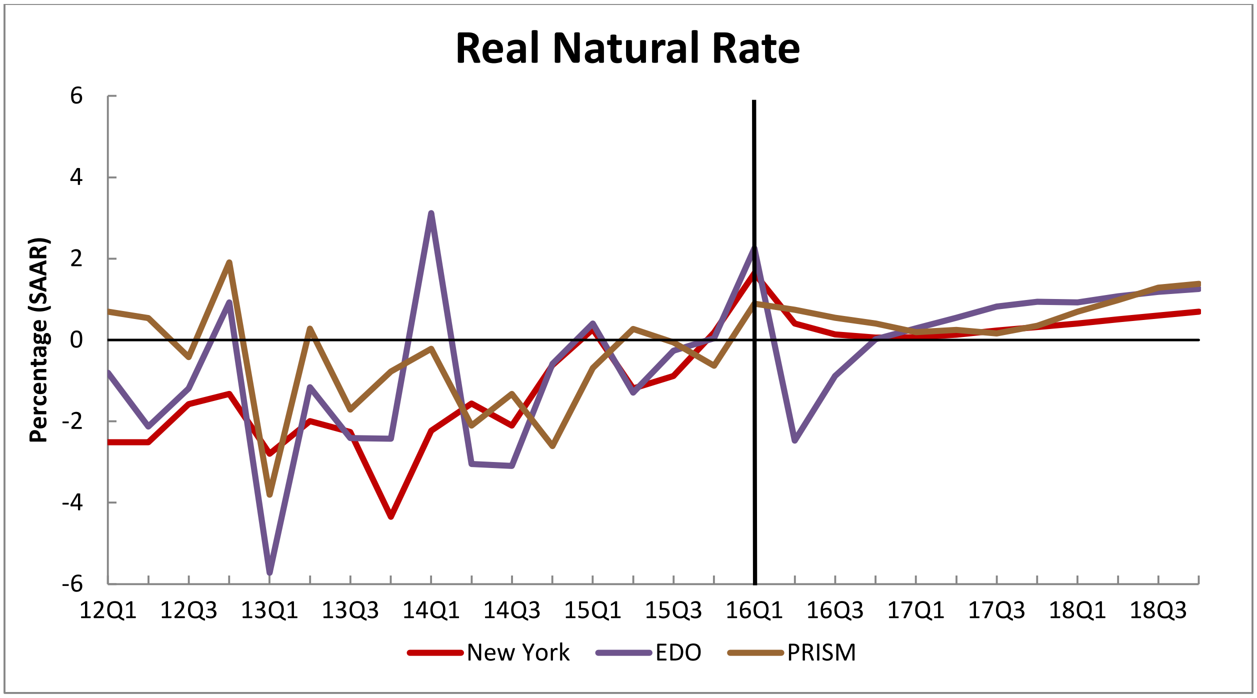
Model	Real Natural Rate of Interest r* (Q4)					
	2016		2017		2018	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**0.0** **(-4.6,4.6)**	0.9 (-4.0,5.7)	**0.9** **(-4.0,6.0)**	1.1 (-4.0,6.1)	**1.3** **(-3.9,6.3)**	1.3 (-3.7,6.5)
New York Fed	**0.1** **(-1.5,1.6)**	-0.1 (-1.4,1.3)	**0.3** **(-1.4,2.1)**	0.3 (-1.2,1.8)	**0.7** **(-1.2,2.5)**	0.6 (-1.0,2.2)
PRISM - Philadelphia Fed	**0.4** **(-2.2,3.4)**	-0.3 (-3.0,2.9)	**0.3** **(-2.5,3.5)**	0.4 (-2.9,3.3)	**1.4** **(-1.8,4.1)**	1.1 (-1.5,5.0)
Median Forecast*	**0.1**	-0.1	**0.3**	0.4	**1.3**	1.1
April Tealbook						

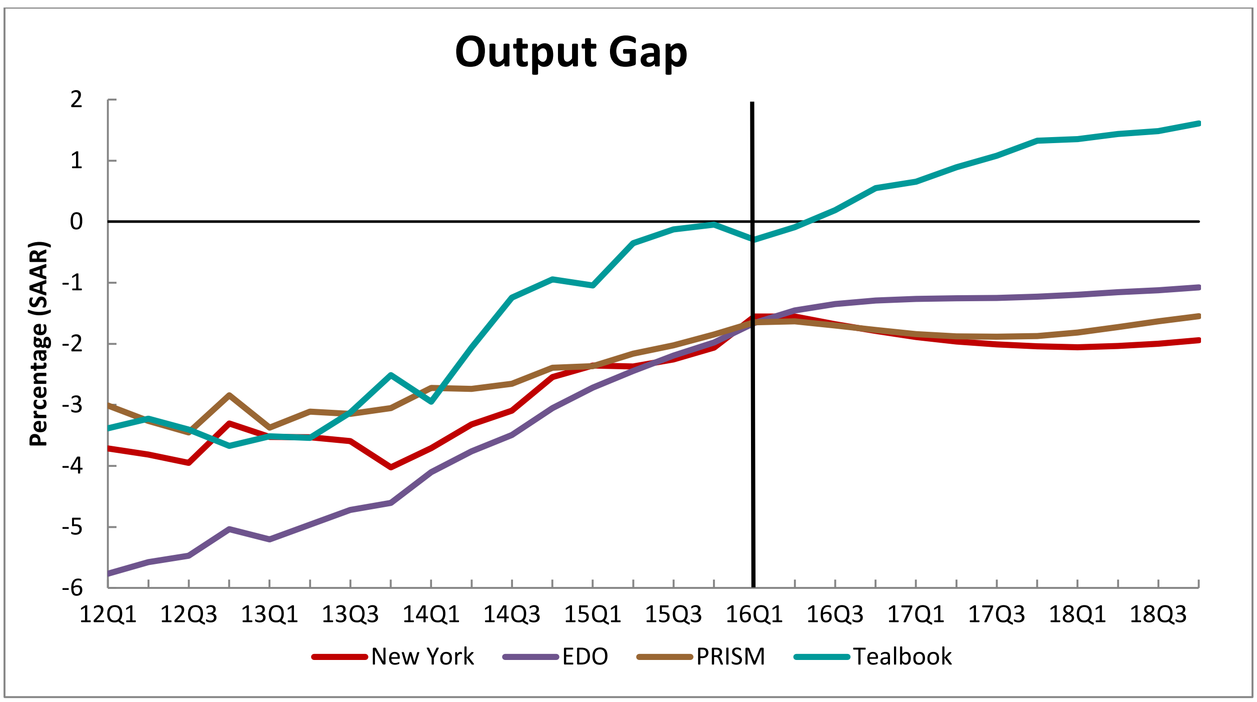
Model	Output Gap (Q4)					
	2016		2017		2018	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**-1.5** **(-2.4,-0.7)**	-1.3 (-2.4,-0.3)	**-1.4** **(-3.0,0.2)**	-1.2 (-3.0,0.5)	**-1.2** **(-3.2,0.8)**	-1.1 (-3.1,0.9)
New York Fed	**-1.8** **(-3.5,-0.6)**	-2.5 (-4.7,-1.1)	**-2.0** **(-5.2,0.0)**	-2.6 (-6.4,-0.3)	**-1.9** **(-5.9,0.7)**	-2.4 (-6.9,0.5)
PRISM - Philadelphia Fed	**-1.8** **(-2.9,-0.5)**	-2.1 (-3.1,-0.5)	**-1.9** **(-3.2,-0.4)**	-1.9 (-3.3,-0.3)	**-1.5** **(-2.8,0.3)**	-1.6 (-3.1,0.2)
Median Forecast*	**-1.8**	-2.1	**-1.9**	-1.9	**-1.5**	-1.6
April Tealbook	**0.5**		**1.3**		**1.6**	


Real GDP Growth
Percentage (SAAR)
5
4
3
2
1
0
-1
-2
-3
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3
New York
EDO
PRISM
Tealbook


Core PCE Inflation
Percentage (SAAR)
5
4
3
2
1
0
-1
-2
-3
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3
New York
EDO
PRISM
Tealbook


Federal Funds Rate
Percentage
5
4
3
2
1
0
-1
-2
-3
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3
New York
EDO
PRISM
Tealbook


Real Natural Rate
Percentage (SAAR)
6
4
2
0
-2
-4
-6
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3
New York
EDO
PRISM


Output Gap
Percentage (SAAR)
2
1
0
-1
-2
-3
-4
-5
-6
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3
New York
EDO
PRISM
Tealbook

Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model forecast conditions on data through 2016:Q1 and a preliminary Tealbook forecast for the second quarter of 2016. Average real GDP growth is 2.5 percent during the forecast period, which is below the estimated trend of 3 percent. Inflation passes the Committee’s 2 percent objective in the fourth quarter of 2016 and then continues to increase, reaching 2.4 percent at the end of 2017; it is projected to remain around that level until the third quarter of 2018. The path for the federal funds rate is upward-sloping over the forecast horizon, reaching 3.2 percent by the third quarter of 2018.

Growth is restrained by extremely persistent adverse movements in the capital-specific risk premium, inferred from the lackluster growth of investment, despite low real interest rates, as well as by the monetary policy shocks. In addition, large negative shocks to technology in recent quarters depress growth in 2016 and early 2017. As these headwinds fade, GDP growth picks up again, reaching 2.7 at the end of 2018.

Largely in reaction to the still-low levels of the employment-population ratio, the model estimates an output gap of negative 1.7 percent in 2016:Q2.[2] With growth slightly below trend, the output gap closes very slowly and remains at negative 1.2 percent by the end of 2018. The real natural rate of interest is projected to increase from its recent lows to 1.3 percent at the end of 2018, 0.8 percent below its steady-state value of 2.1 percent. The natural rate is held down by the capital risk-premium shocks as well as by an elevated aggregate risk premium.

[2] The output gap is defined as actual output minus the level of output prevailing in the absence of nominal rigidities and inefficient markup shocks.

The FRBNY Model

The FRBNY model forecasts are obtained using data released through 2016Q1, augmented for 2016Q2 with the FRBNY staff forecasts (as of May 27) 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 2016Q2 averages up to May 27.

The model projects real GDP growth of 1.6 percent in 2016 (Q4/Q4), slightly lower than the 1.8 percent forecast in March, and of 2.2 percent in 2017, the same as in March and December. The growth outlook is revised slightly upward from 2.4 percent to 2.5 percent in 2018 and is expected to move to a more robust 2.6 percent in 2019. By contrast, the projections of inflation for 2016 (Q4/Q4) are revised upward to 1.6 percent from 1.3 percent in March, while forecasts for the years 2017-2019 remain unchanged at 1.2, 1.3 and 1.4 percent, respectively, on a Q4/Q4 basis.

The near term revisions in the forecasts partly reflect surprises in the data releases for 2016Q1 relative to the March FRBNY staff forecast for that quarter: GDP growth was about 0.6 percentage point lower, while inflation was 0.5 percentage points higher. In addition to these changes, the conditioning on 2016Q2 May FRBNY staff forecasts has a substantial impact on the current growth forecast. In fact, without conditioning, the forecast for 2016 real GDP growth is 2.2 percent (Q4/Q4), and therefore above the March projection. Conversely, the unconditional inflation forecast is roughly the same as the conditional forecast.

These near term changes in output growth and inflation are interpreted by the model as temporary. A slowdown in productivity and the abating of negative mark-up shocks, possibly capturing the reversal in energy prices, are the primary temporary factors behind the growth slowdown in the near term and the uptick in inflation. Overall, the model forecasts remain in line with the narrative that we have been describing for quite some time. The headwinds that slowed down the economy in the aftermath of the financial crisis were finally abating, but the swings in financial markets experienced in the first few months of 2016, and the associated widening of credit spreads have slowed the normalization process. Despite this setback, the model expects a rebound in growth in the second part of the year, so that the medium term forecast remains, as in

March, one of steady, gradual expansion. At the same time, financial conditions remain tight compared to historical standards, preventing a more rapid recovery in economic activity. As a result, the output gap – the difference between output and natural output – continues to be negative throughout the forecasting period. Relative to March, however, the output gap is smaller (partly because of the lower than expected productivity) and is expected to gradually shrink to reach -1.7 percent in 2019Q4; there is however a considerable degree of uncertainty surrounding the forecast, as outlined below. The real natural rate of interest is currently expected to reach 0.1 percent by the end of 2016 and is projected to increase slowly over the next few years, reaching 0.3, 0.7 and 0.9 percent at the end of 2017, 2018 and 2019, respectively.

Given how close the March and June forecasts are, it is not surprising that the projected path for the federal funds rate is roughly unchanged. In the model projections the federal funds rate reaches 0.6 percent in 2016Q4, and little over 2 percent towards the end of 2018. Despite this subdued path, the projected FFR implies a path for the ex-ante real interest rate that is somewhat below the natural rate of interest in the short run (-0.6 versus 0.1 percent in 2016Q4, respectively) but close to it by the end of 2017 (in 2018Q4 the two rates are 0.8 and 0.7 percent respectively).

The projections are surrounded by notable uncertainty. The width of the 68 percent probability interval for GDP growth is 2.8 percentage points in 2016, ranging from 0.0 to +2.8 percent, and widens to 5.5 percentage points in 2018, from -0.3 to +5.2 percent. Uncertainty for the real natural rate and the output gap is also extremely large. For 2018, the 68 percent bands for the natural rate range from -1.2 to +2.5 percent, while those for the output gap range from -5.9 to +0.7 percent. The 68 percent probability intervals for inflation range from 1.2 to 1.9 percent in 2016 and from 0.2 to 2.4 percent in 2018. Of notice, uncertainty about medium term inflation has increased somewhat relative to March (it ranged from 0.4 to 2.1 in 2018).

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2016Q1 that are then supplemented with a 2016Q2 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output growth will accelerate gradually from a 2 percent pace in 2015 to 3.4 percent in 2018. The nowcast pins down real output growth in 2016Q2 at 2.5 percent, but growth then rises to 2.7 percent in 2017Q1 and peaks at 3.4 percent in mid-2018. Core inflation remains contained and runs at 2 percent over the next three years. The PRISM projection now has the funds rate following an estimated policy rule through the forecast horizon: the federal funds rate rises to 1.6 percent in 2016Q4 and then advances steadily to reach 3.6 percent in 2018Q4.

For this forecast round we have again included estimates of the natural rate of interest and the output gap as determined from the model. The natural rate of interest – the rate of interest that would prevail if wages and prices were fully flexible – is estimated at 0.74 percent in 2016Q2. As output growth strengthens and the economy normalizes to trend, the natural rate rises over the next three years to reach about 1.4 percent at the end of 2018. Our estimates of the output gap are derived from the log deviation of real output from its flexible-price counterfactual level. The estimated output gap is at -1.6 percent in 2016Q2 and is little changed over the forecast horizon, reaching -1.5 percent at the end of 2018.

According to PRISM, negative shocks to TFP growth and monetary policy were the most important factors dampening real output growth over the course of 2015. Positive and partially offsetting contributions come from the rebound in hours worked and investment. TFP shocks exert a modest drag on output growth in 2016 as do monetary policy and financial shocks. By mid-2017 though, output growth rises above the model estimated trend rate. Investment shocks, government spending shocks, and labor supply shocks continue to make a positive contribution to output growth over the forecast horizon. Consumption growth remains below its steady state level until the end of the forecast horizon, held down by TFP shocks, investment shocks, and the rising federal funds rate. On balance, the model continues to imply a de-trended level of output that is below its steady state: and an important factor in accounting for this output gap is the low level of aggregate hours worked, which the model generates through a combination of labor supply shocks and government spending shocks.

The 2016Q2 nowcast for core PCE inflation is 1.6 percent. The model predicts that inflation rises to about 2 percent in 2016Q3 and runs at that pace through the remainder of the forecast horizon, as upward pressure on prices from investment growth and the renormalization of the labor market is largely offset by the slow unwinding of past financial shocks, and a rising funds rate.

In 2016Q4 the funds rate averages 1.6 percent and rises to 3 percent by the end of 2017 – about the same pace of normalization as in the March forecast. The model puts relatively little weight on output dynamics in the estimated policy rule. Consequently, the shocks that account for the dynamics of the federal funds rate are largely the same as those that account for the dynamics of inflation.