BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM
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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

March 4, 2016

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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 2015Q4 and conditioning assumptions or 'nowcasts' for 2016Q1, 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 January Tealbook forecast (the most recent Tealbook forecast available to us), as well as the DSGE model forecasts prepared for the December 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 its natural level, 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 1.8 and 2.6 percent, a narrower range compared to that reported in December (1.9 to 2.9 percent). Over the entire forecast horizon, the models individually predict rising growth, though the median projection calls for 2.3 percent growth in 2016 and 2017, and a slight acceleration to 2.6 percent in 2018. Compared to the December median, growth over the forecast horizon is now projected to be lower by about 0.5 percentage points in 2016 and 2017, and 0.3 percentage points in 2018. While all the models show a downward revision to 2016 output growth, only EDO has pared back its forecast for 2017 and 2018. FRBNY now predicts somewhat faster growth in 2018 compared to December while

PRISM is unchanged. PRISM continues to show the most optimistic forecast with growth at an above 3 percent pace in 2017 and 2018. EDO and FRBNY forecast growth at 2.2 to 2.3 percent, respectively, in 2017, rising to 2.5 and 2.6 percent, respectively, in 2018. The DSGE model forecasts are all stronger than the January Tealbook, which has output growth at 2.0 percent in 2017 and 1.8 percent in 2018.

Turning to the inflation projections, the median of the DSGE models' core inflation forecast is 1.7 percent for 2016, the same as the December projection and 0.4 percentage points higher than the January Tealbook projection. That reflects an increase in EDO's and FRBNY's projections and a decline in PRISM's relative to December. For the remainder of the forecast horizon, the DSGE median forecast is slightly lower (1.8 versus 2.0 percent in 2017 and 2.0 versus 2.1 percent in 2018) as downward revisions of PRISM dominate increases in EDO's and essentially unchanged projections of FRBNY. Overall, these inflation forecasts remain somewhat stronger than the January Tealbook, which has core inflation at 1.6 percent in 2017 and 1.9 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 gap.

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 near zero or higher in the current quarter. However, according to the FRBNY DSGE model, the tightening in financial conditions since the summer 2015 has reignited some of these headwinds and is responsible for a reduction in near-term forecasts of GDP growth and of the natural rate of interest. Over time, these headwinds will continue to abate and the estimated natural rates in all models are projected to rise to positive territory, albeit slowly.

While the models agree that the current level of the output gap is about -2 percent, the speed at which the gap is projected to close over the next three years varies across models. EDO has the gap at -1.3 percent by 2016Q4, compared to the more gradual pace for PRISM (-2.1 percent) and FRBNY (-2.5 percent). By 2018Q4 EDO has the gap edging down slightly to -1.1 percent, compared to PRISM at -1.6 percent, and FRBNY at a more substantial -2.4 percent. FRBNY's projections remain the most pessimistic, attributing to the most 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 January Tealbook output gap projection is much more optimistic than the DSGE models, with a positive gap of 0.7 percentage points in 2016Q4, rising to 1.3 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. In PRISM, the pace of renormalization has shifted down and is now similar to EDO – both models predict that the funds rate will be at 2.9 percent in 2017Q4 and 3.5 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 2.1 percent in 2018Q4. The January 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.
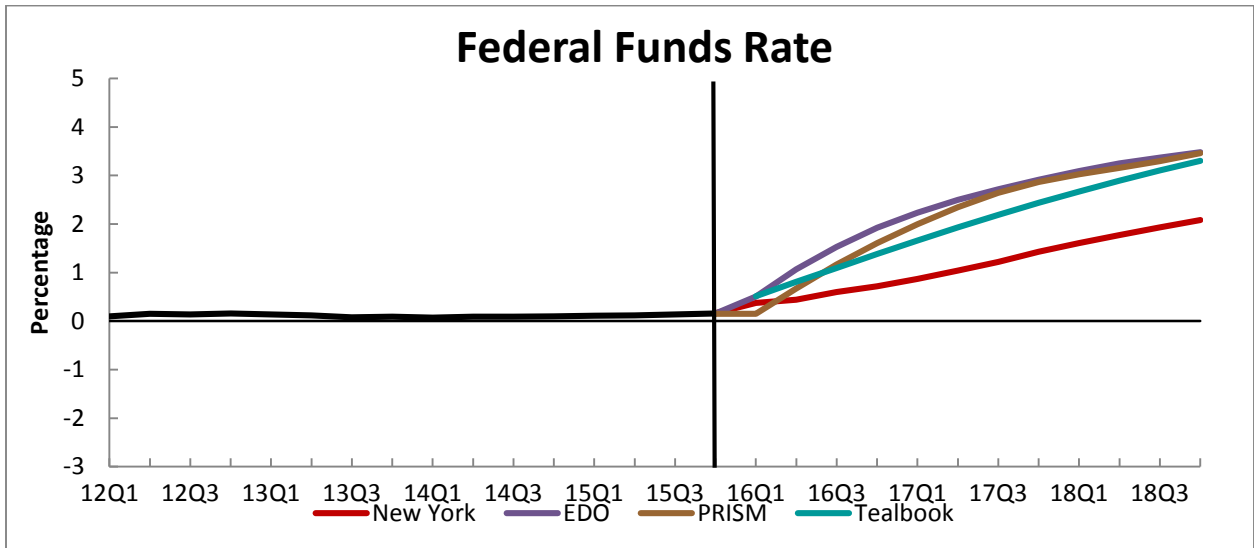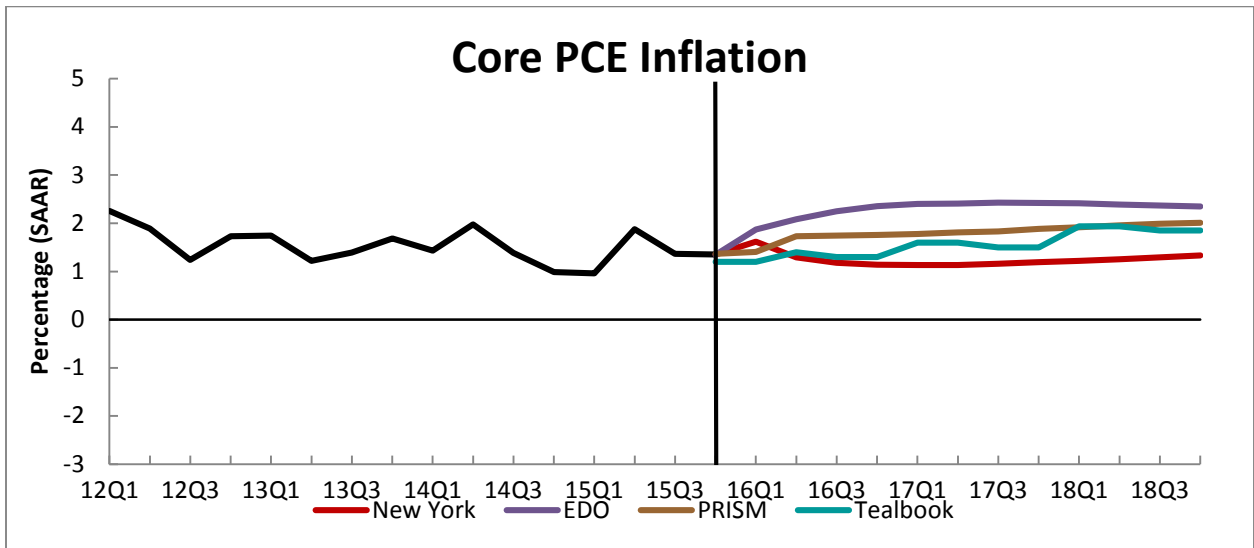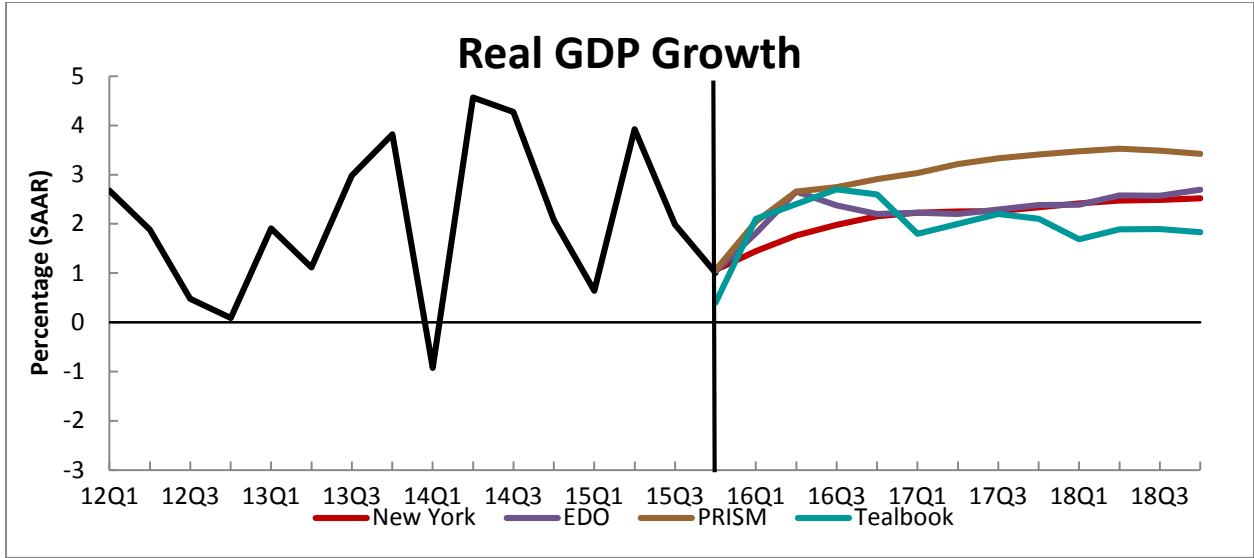
Forecasts

Model	Output Growth (Q4/Q4)					
	2016		2017		2018	
	March	*December*	**March**	*December*	**March**	*December*
EDO - Board of Governors	**2.3** **(0.8,3.8)**	2.8 (0.9,4.7)	**2.3** **(0.2,4.3)**	2.8 (0.6,4.9)	**2.6** **(0.4,4.7)**	2.9 (0.8,5.1)
New York Fed	**1.8** **(-0.5,3.2)**	1.9 (-1.0,3.8)	**2.2** **(-0.7,4.5)**	2.2 (-0.8,4.5)	**2.5** **(-0.3,5.0)**	2.3 (-0.4,5.0)
PRISM - Philadelphia Fed	**2.6** **(0.4,4.9)**	2.9 (-0.2,6.1)	**3.3** **(0.0,6.9)**	3.3 (-0.1,7.1)	**3.5** **(0.0,7.2)**	3.5 (-0.2,7.2)
Median Forecast*	**2.3**	2.8	**2.3**	2.8	**2.6**	2.9
January Tealbook	**2.4**		**2.0**		**1.8**	

Model	Core PCE Inflation (Q4/Q4)					
	2016		2017		2018	
	March	*December*	**March**	*December*	**March**	*December*
EDO - Board of Governors	**2.1** **(1.7,2.6)**	1.7 (1.1,2.3)	**2.4** **(1.6,3.3)**	2.0 (1.2,2.9)	**2.4** **(1.4,3.3)**	2.1 (1.1,3.1)
New York Fed	**1.3** **(0.8,1.8)**	1.0 (0.3,1.7)	**1.2** **(0.3,1.9)**	1.1 (0.2,1.9)	**1.3** **(0.4,2.1)**	1.3 (0.4,2.2)
PRISM - Philadelphia Fed	**1.7** **(0.8,2.6)**	2.2 (0.9,3.4)	**1.8** **(0.4,3.5)**	2.1 (0.5,3.7)	**2.0** **(0.2,3.6)**	2.2 (0.5,4.0)
Median Forecast*	**1.7**	1.7	**1.8**	2.0	**2.0**	2.1
January Tealbook	**1.3**		**1.6**		**1.9**	

Model	Federal Funds Rate (Q4)					
	2016		2017		2018	
	March	*December*	**March**	*December*	**March**	*December*
EDO - Board of Governors	**1.9** **(0.9,2.9)**	1.6 (0.4,2.8)	**2.9** **(1.3,4.5)**	2.6 (1.0,4.3)	**3.5** **(1.5,5.4)**	3.3 (1.4,5.1)
New York Fed	**0.7** **(0.1,2.1)**	1 (0.1,2.7)	**1.4** **(0.2,3.4)**	1.7 (0.3,3.8)	**2.1** **(0.5,4.2)**	2.3 (0.7,4.5)
PRISM - Philadelphia Fed	**1.6** **(0.3,2.8)**	2.5 (1.0,4.0)	**2.9** **(0.5,5.0)**	3.7 (1.0,5.9)	**3.5** **(0.7,6.3)**	4.2 (1.3,7.0)
Median Forecast*	**1.6**	1.6	**2.9**	2.6	**3.5**	3.3
January Tealbook	**1.4**		**2.4**		**3.3**	

Model	Real Natural Rate of Interest r* (Q4)					
	2016		2017		2018	
	March	*December*	**March**	*December*	**March**	*December*
EDO - Board of Governors	**0.9** (**-4.0,5.7**)	0.4 (-4.4,5.2)	**1.1** (**-4.0,6.1**)	0.9 (-4.3,5.8)	**1.3** (**-3.7,6.5**)	1.3 (-3.9,6.3)
New York Fed	**-0.1** (**-1.4,1.3**)	0.3 (-1.1,1.6)	**0.3** (**-1.2,1.8**)	0.6 (-0.9,2.0)	**0.6** (**-1.0,2.2**)	0.8 (-0.8,2.3)
PRISM - Philadelphia Fed	**-0.3** (**-3.0,2.9**)	0.2 (-2.9,3.3)	**0.4** (**-2.9,3.3**)	1.0 (-2.3,4.4)	**1.1** (**-1.5,5.0**)	1.6 (-1.7,5.0)
Median Forecast*	**-0.1**	0.3	**0.4**	0.9	**1.1**	1.3
January Tealbook						

Model	Output Gap (Q4)					
	2016		2017		2018	
	March	*December*	**March**	*December*	**March**	*December*
EDO - Board of Governors	**-1.3** (**-2.4,-0.3**)	-1.4 (-2.7,-0.2)	**-1.2** (**-3.0,0.5**)	-1.1 (-2.9,0.7)	**-1.1** (**-3.1,0.9**)	-0.8 (-2.9,1.2)
New York Fed	**-2.5** (**-4.7,-1.1**)	-2.8 (-5.6,-1.2)	**-2.6** (**-6.4,-0.3**)	-2.8 (-7.0,-0.2)	**-2.4** (**-6.9,0.5**)	-2.5 (-7.4,0.6)
PRISM - Philadelphia Fed	**-2.1** (**-3.1,-0.5**)	-0.9	**-1.9** (**-3.3,-0.3**)	-0.9	**-1.6** (**-3.1,0.2**)	-0.8
Median Forecast*	**-2.1**	-1.4	**-1.9**	-1.1	**-1.6**	-0.8
January Tealbook	**0.7**		**1.1**		**1.3**	

Real GDP Growth

Core PCE Inflation

Federal Funds Rate

Real Natural Rate

Output Gap
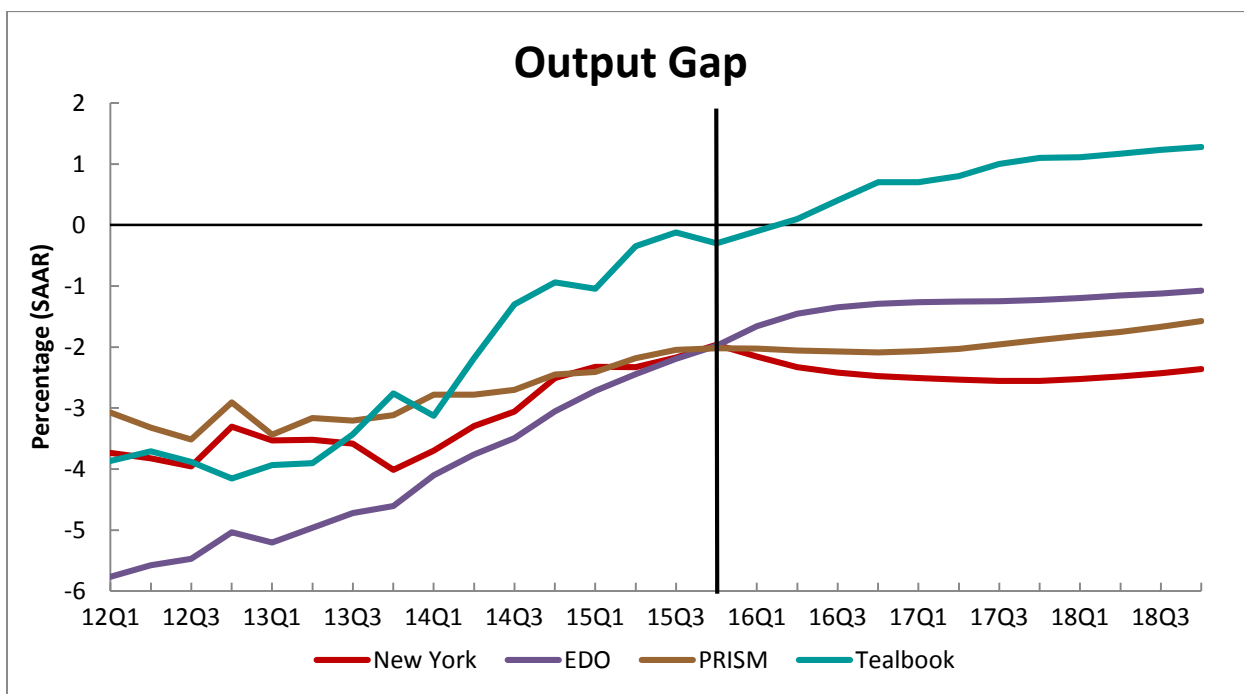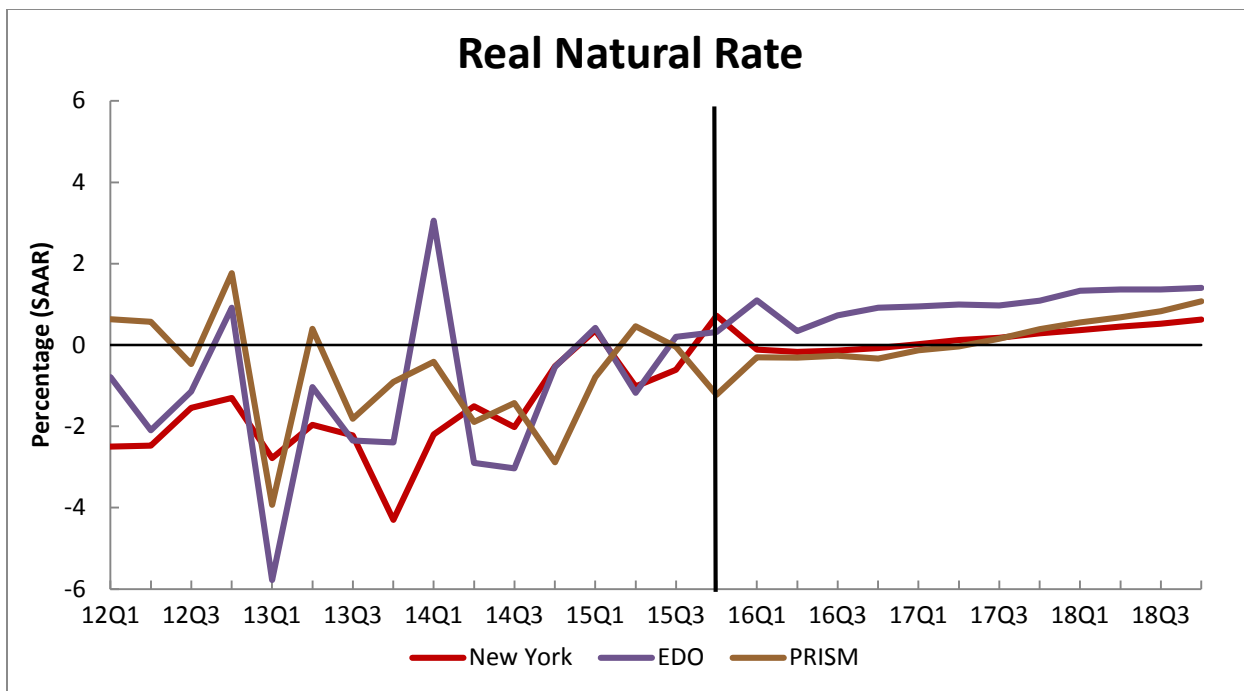
Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model forecast conditions on data through 2015Q4 and a preliminary Tealbook forecast for the first quarter of 2016. Average real GDP growth is 2.4 percent during the forecast period, which is below the estimated trend of 3 percent. Inflation passes the Committee's 2 percent objective in the second quarter of 2016 and then continues to increase, reaching 2.4 percent in the last quarter of 2016; it is projected to remain at that level in 2017 and 2018. The path for the federal funds rate is upward-sloping over the forecast horizon, surpassing 3 percent by early 2018.

Growth is restrained by the effects of 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 also 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 -1.7 percent in 2016Q1.[2] With growth slightly below trend, the output gap closes very slowly and remains at -1.1 percent by the end of 2018. The real natural rate of interest is projected to increase from 0.3 percent at the end of 2015 to 1.4 percent at the end of 2018, 0.7 percentage points 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. The relatively strong estimate in 2016Q1—1.1 percent—can be attributed to a large negative technology shock in that quarter, which, by transiently decreasing the price of capital, generates expectations of strong capital gains, thus raising the natural rate of interest.

The nowcast for 2016Q1 GDP is weaker than the model expected in December, while the nowcast for 2016Q1 core inflation is stronger at 1.9 percent. Inferring a sizable negative innovation to technology, the model forecast for GDP growth in 2016 and 2017 is revised down

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[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.

to around ½ percent. The same innovation to technology raises projected inflation over the forecast horizon, by around 35 basis points on average.

The FRBNY Model

The FRBNY model forecasts are obtained using data released through 2015Q4, augmented for 2016Q1 with the FRBNY staff forecasts (as of February 26) 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 2016Q1 averages up to February 26.

Projections for real growth and inflation are little changed relative to December. The model projects real GDP growth of 1.8 percent in 2016 (Q4/Q4), slightly lower than the 1.9 percent forecast in December, and of 2.2 percent in 2017, unchanged relative to December. The growth outlook is revised upward from 2.3 percent to 2.4 percent in 2018 and is expected to move to a more robust 2.6 percent in 2019. By contrast, the projections of inflation are revised marginally upward in 2016 and 2017 (Q4/Q4), to 1.3 and 1.2 percent, respectively, from 1.0 and 1.1 percent, respectively, in December. After that, inflation is forecast to remain around 1.3 percent in 2018 and to move up to 1.4 percent in 2019.

The near term revisions in the forecasts reflect mostly surprises in the data releases for 2015Q4 relative to the December FRBNY staff forecast for that quarter: GDP growth printed about 1 percent lower, while inflation was 10 basis points higher. Relatively tight financial conditions, measured in the model by the Baa-Treasury spread, which remained elevated in the second half of 2015 and into 2016, continue to restrain growth forecasts. A negative productivity shock also impacts GDP growth in the near term. Nonetheless, relative to December, GDP growth projections for the latter part of the forecast horizon moved slightly up, indicating that the model interprets financial headwinds as relatively transitory. The slight increase in the medium term inflation forecasts is interpreted by the model as due to a temporary abating of negative mark-up shocks.

Overall, the forecasts remain in line with the narrative that we have been describing in the past. 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 past few months, and the associated widening of credit spreads have slowed the normalization process. As a result, the output gap – the difference between output and natural output – continues to be negative throughout the forecasting period. Relative to December, however, the output gap is smaller and is expected to gradually shrink to reach -2.0 percent in 2019Q4. Uncertainty about the level of the output gap remains extremely large, as outlined below. The real natural rate of interest is expected to remain negative through the end of 2016 (-0.1 percent) and is projected to increase at a slower pace relative to the December forecast, reaching 0.3, 0.6 and 0.8 percent at the end of 2017, 2018 and 2019, respectively.

Consistent with these forecasts, the projected path for the federal funds rate is a tad shallower than forecasted in December. In the current projections the federal funds rate reaches 2 percent towards the end of 2018, about two quarters later than forecasted in December. The shallower path supports the rise in inflation and the slow reduction of the output gap. Despite this subdued path, the projected FFR implies a path for the ex-ante real interest rate that is close to the estimated natural rate of interest. This suggests that the slow renormalization path for the federal funds rate doesn't represent a particularly accommodative monetary policy stance.

The projections are surrounded by notable uncertainty. The width of the 68 percent probability interval for GDP growth is 3.8 percentage points in 2016, ranging from -0.5 to +3.2 percent, and widens to 5.4 percentage points in 2018, from -0.3 to +5.0 percent. Uncertainty for the real natural rate and the output gap is also extremely large. For 2018, the 68 percent bands for the natural rate range from -1.1 to +2.0 percent, while those for the output gap range from -7.1 to -0.1 percent. The 68 percent probability intervals for inflation range from 0.8 to 1.8 percent in 2016 and from 0.4 to 2.1 percent in 2018.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2015Q4 that are then supplemented with a 2016Q1 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output growth will accelerate gradually from a 1.9 percent pace in 2015 to 3.5 percent in 2018. The nowcast pins down real output growth in 2016Q1 at 2 percent, but growth then rises to 2.7 percent in 2016Q2 and then to a peak of about 3.5 percent in early 2018. Core inflation remains contained below 2 percent over the next three years. The funds rate path, obtained from the model estimated policy rule, shows a steady increase in the federal funds rate to 1.6 percent in 2016Q4 and 3.5 percent in 2018Q4.

For this forecast round we have 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 -0.5 percent in 2015Q4. As output growth strengthens and the economy normalizes to trend, the natural rate rises over the next three years to reach about 1.6 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. Since PRISM does not estimate a great deal of wage and price stickiness in the economy, the estimated output gap tends to be modest and is at -0.3 percent in 2016Q1. The output gap shrinks slowly over the forecast horizon from -2.0 percent in 2016Q1 to -1.6 percent in 2018Q4.

According to PRISM, negative shocks to TFP growth, monetary policy, and financial conditions were the most important factors dampening real output growth over the course of 2015. Positive and offsetting contributions come from the rebound in hours worked and investment. As TFP shocks wane, output growth rises above steady state growth in 2017. Investment shocks, government spending shocks, and labor supply shocks make a positive contribution to output growth over the forecast horizon, while the rise in the federal funds rate and financial shocks dampens growth over the next three years. 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 below its steady state: an important factor in accounting for the 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. PRISM estimates the current output gap at about -2 percent, falling to -1.6 percent in 2018Q4.

The 2015Q4 nowcast for core PCE inflation is 1.4 percent. The model predicts that inflation rises to about 1.8 percent by the end of 2016. With inflation running at about trend in 2017 and 2018, PRISM has upward pressure on prices from the renormalization of the labor market being largely offset by the slow unwinding of past financial shocks, and a rising funds rate.

The forecast is implemented with an unconstrained federal funds rate path going forward. In 2016Q4 the funds rate averages 1.6 percent and rises to 2.9 percent by the end of 2017. 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.