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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 provide a summary of the forecasts and then describe each of them 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 2016Q3 and conditioning assumptions or “nowcasts” for 2016Q4 where the sources of the nowcasts 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. For the sake of comparison, the tables include the October Tealbook forecast (the most recent Tealbook forecast available to us at the time of writing), as well as the DSGE model forecasts prepared for the September 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 deviations of actual output from the natural level of output, the latter again defined as the level of output that would prevail if prices and wages were fully flexible.

Turning first to GDP growth, the median forecast is largely unchanged from September and has growth accelerating from 1.8 percent in 2016 to 2.7 percent in 2017-2018, and to 2.9 percent in 2019. Disagreement across the forecasts remains modest. On the low end, FRBNY has output growth at 1.9 percent in 2017, rising to 2.7 percent in 2019. On the high end, PRISM has output growth at 2.7 percent in 2017, rising to 3.3 percent in 2019. The Tealbook forecast is on balance weaker than the three models with a growth path that decelerates from 2.2 percent in 2017 to 1.7 percent in 2019.

Turning to inflation, the disagreement among models is slightly more pronounced than for GDP growth, and is not much changed from September. In FRBNY, the return of core PCE inflation to mandate consistent levels continues at a glacial pace and from a low base, given the model's projection of relatively subdued output growth and persistently negative output gaps. In contrast, EDO and PRISM predict that inflation will be back to 2 percent in 2017, followed by a mild overshooting. Both EDO and PRISM project a stronger inflation path than does the October Tealbook, while FRBNY continues to foresee a weaker path.

The three models show similar assessments of the current level and the future expected evolution of both r^* and the output gap. Looking at the medians across the three models' point forecasts, the real natural rate is projected to be slightly positive at the end of 2016 and to rise gradually to 1.4 percent in 2019, with a fairly narrow range of 1 to 1.4 percent. As for the output gap, the three models estimate it to be negative at present and to remain so throughout the forecast horizon. The estimates are slightly more pessimistic on the output gap than they were in September. As was the case last time, the models' assessment of economic slack is markedly different from the Tealbook, whose output gap estimate takes more signal from unemployment and is both positive and growing steadily over the next two years.

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 contributed to depress economic activity over the course of the recovery, except in its very early phase. The restraint due to tight 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, the models project that these headwinds will continue to abate, contributing to lifting the natural rate and economic activity more broadly.

The expected speed of normalization in the federal funds rate varies across models, consistent with their assessments of the speed at which economic activity and especially inflation rebound. PRISM continues to feature the most rapid normalization, with the funds rate reaching 2.5 percent at the end of 2017, and then climbing to 3.8 percent by the end of 2019. EDO projects a somewhat shallower path, reaching 2 percent at the end of 2017 and 3.6 percent at the

end of 2019. FRBNY expects a more gradual pace of tightening with the federal funds rate at 1.4 percent at the end of 2017 and 2.7 percent at the end of 2019. As a result, the FRBNY interest rate path is close to the pace assumed in the October Tealbook.

Forecasts

Model	Real GDP Growth (Q4/Q4)							
	2016		2017		2018		2019	
	Dec	Sept	Dec	Sept	Dec	Sept	Dec	Sept
EDO - Board of Governors	1.9 (1.9,1.9)	2.0 (1.3,2.6)	2.8 (0.9,4.7)	2.7 (0.7,4.8)	2.7 (0.6,4.8)	2.7 (0.6,4.8)	2.9 (0.7,5.0)	2.9 (0.8,5.0)
FRBNY - New York Fed	1.8 (1.8,1.8)	1.9 (1.0,2.6)	1.9 (-0.8,4.1)	2.3 (-0.7,4.6)	2.5 (-0.3,5.1)	2.6 (-0.3,5.2)	2.7 (-0.1,5.5)	2.7 (-0.2,5.5)
PRISM - Philadelphia Fed	1.8 (1.8,1.8)	2.1 (1.5,2.8)	2.7 (-0.2,5.8)	2.9 (-0.2,6.2)	3.2 (-0.2,6.7)	3.2 (-0.0,7.0)	3.3 (-0.1,7.1)	3.2 (-0.3,6.9)
Median*	1.8	2.0	2.7	2.7	2.7	2.7	2.9	2.9
October Tealbook	1.7		2.2		1.9		1.7	

Model	Core PCE Inflation (Q4/Q4)							
	2016		2017		2018		2019	
	Dec	Sept	Dec	Sept	Dec	Sept	Dec	Sept
EDO - Board of Governors	1.8 (1.8,1.8)	1.7 (1.5,1.8)	2.0 (1.4,2.6)	2.1 (1.3,2.8)	2.2 (1.4,3.1)	2.3 (1.3,3.2)	2.2 (1.3,3.2)	2.2 (1.2,3.2)
FRBNY - New York Fed	1.8 (1.8,1.8)	1.6 (1.4,1.8)	1.4 (0.6,2.1)	1.3 (0.5,2.1)	1.4 (0.4,2.3)	1.4 (0.3,2.4)	1.5 (0.3,2.6)	1.5 (0.3,2.7)
PRISM - Philadelphia Fed	1.8 (1.8,1.8)	1.9 (1.6,2.2)	2.0 (0.9,3.3)	2.0 (0.7,3.3)	2.1 (0.5,3.6)	2.1 (0.5,3.7)	2.2 (0.6,3.9)	2.2 (0.4,3.8)
Median*	1.8	1.7	2.0	2.0	2.1	2.1	2.2	2.2
October Tealbook	1.7		1.7		1.8		1.9	

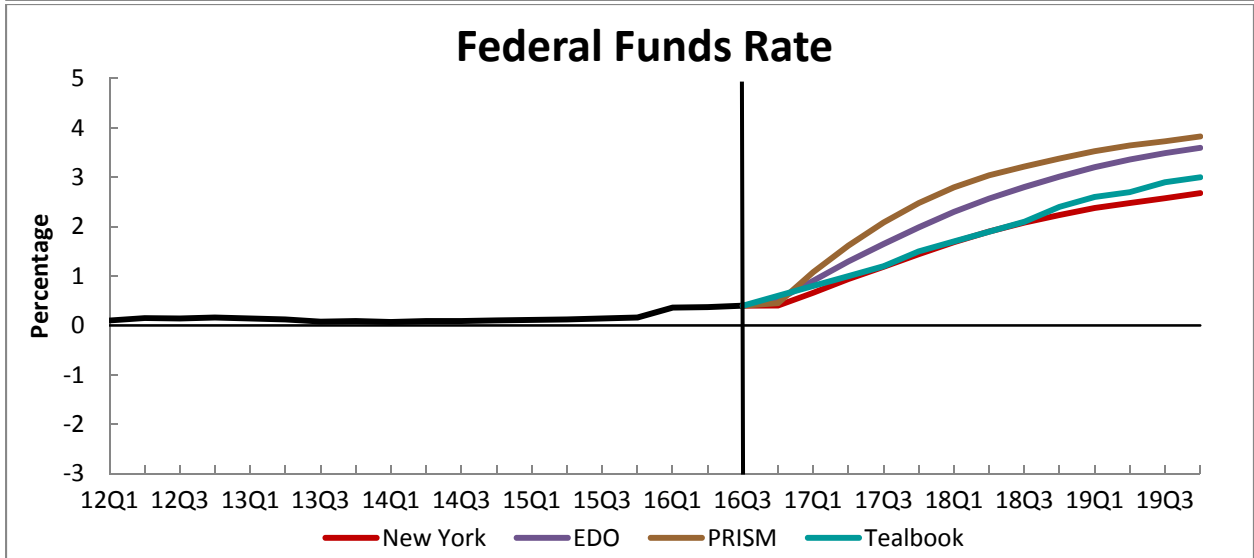
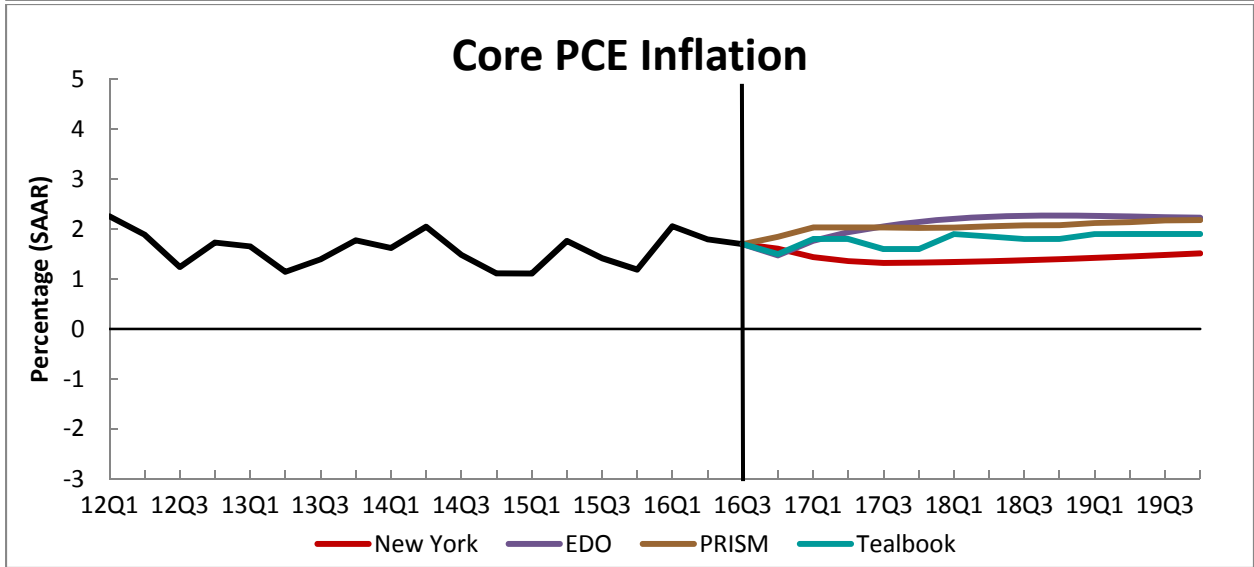
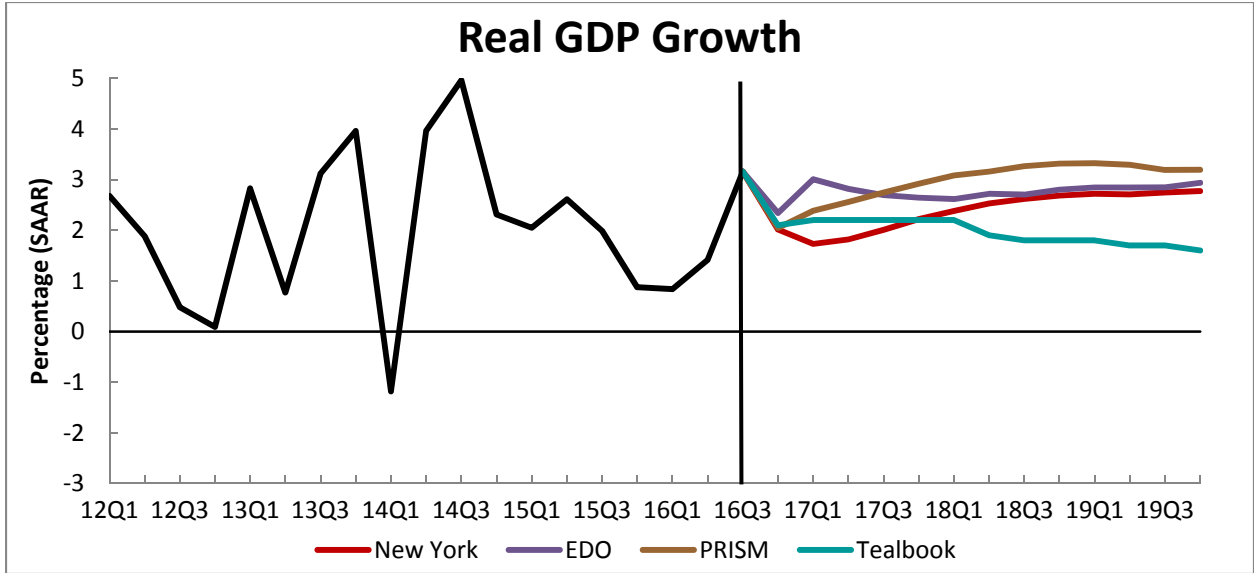
Model	Federal Funds Rate (Q4)							
	2016		2017		2018		2019	
	Dec	Sept	Dec	Sept	Dec	Sept	Dec	Sept
EDO - Board of Governors	0.5 (0.5,0.5)	0.8 (0.3,1.3)	2.0 (0.8,3.2)	2.3 (0.9,3.6)	3.0 (1.3,4.8)	3.2 (1.4,5.0)	3.6 (1.7,5.5)	3.7 (1.7,5.6)
New York Fed	0.4 (0.4,0.4)	0.6 (0.1,1.4)	1.4 (0.3,2.9)	1.5 (0.3,3.1)	2.2 (0.7,4.0)	2.2 (0.7,4.1)	2.7 (0.9,4.6)	2.7 (0.9,4.7)
PRISM - Philadelphia Fed	0.5 (0.5,0.5)	1.1 (0.5,1.6)	2.5 (1.1,3.9)	2.8 (1.1,4.5)	3.4 (0.9,5.5)	3.6 (1.2,6.1)	3.8 (1.0,6.6)	4.0 (0.9,6.4)
Median*	0.5	0.8	2.0	2.3	3.0	3.1	3.6	3.7
October Tealbook	0.6		1.5		2.4		3.0	

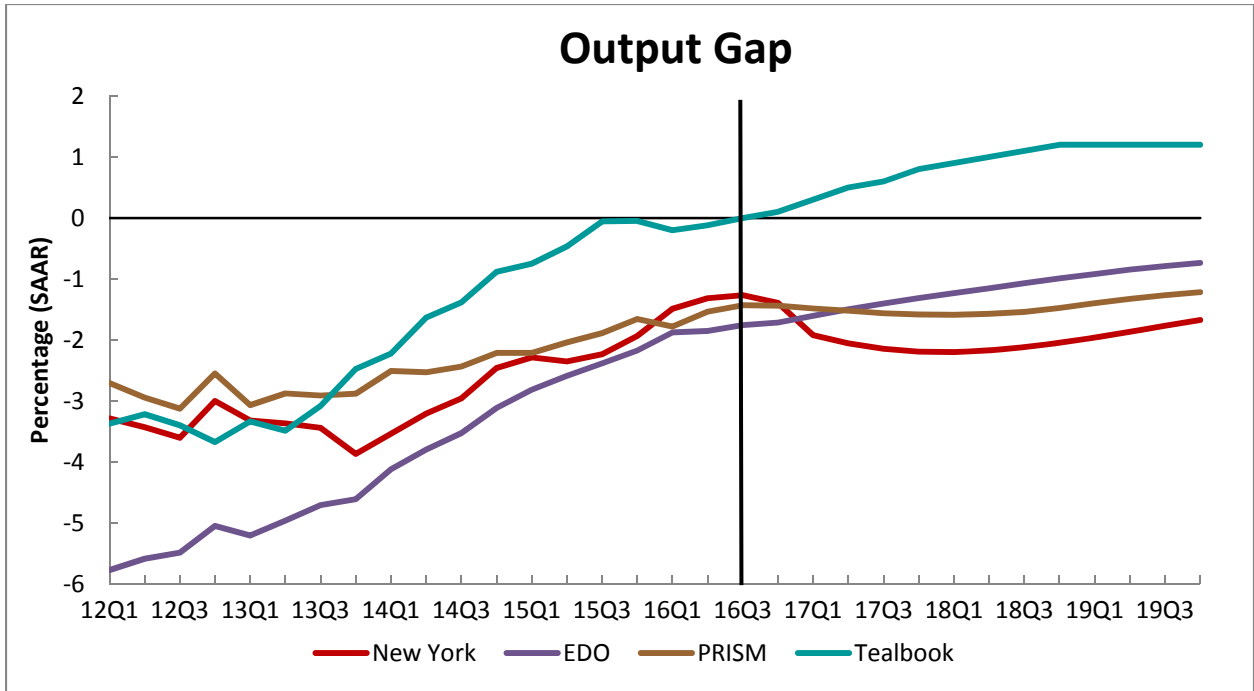
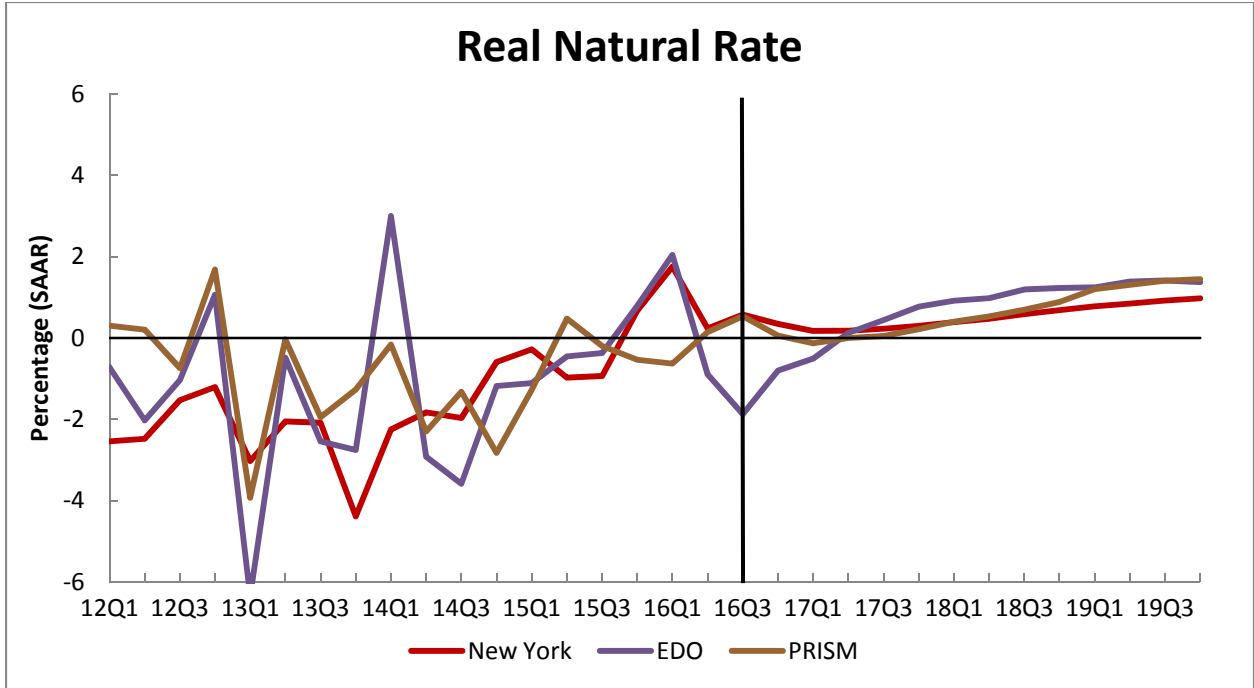
Model	Real Natural Rate of Interest r* (Q4)							
	2016		2017		2018		2019	
	Dec	Sept	Dec	Sept	Dec	Sept	Dec	Sept
EDO - Board of Governors	-0.8 (-2.5,0.9)	-0.2 (-4.3,4.0)	0.8 (-4.0,5.5)	0.9 (-3.8,5.6)	1.2 (-3.8,6.3)	1.4 (-3.6,6.4)	1.4 (-3.7,6.3)	1.4 (-3.7,6.6)
New York Fed	0.3 (-1.0,1.7)	0.3 (-1.2,1.7)	0.3 (-1.4,2.1)	0.4 (-1.4,2.2)	0.7 (-1.3,2.6)	0.7 (-1.2,2.7)	1.0 (-1.1,3.0)	1.0 (-1.0,3.0)
PRISM - Philadelphia Fed	0.1 (-2.2,2.0)	0.3 (-2.7,2.6)	0.2 (-3.0,3.4)	0.5 (-2.6,3.4)	0.9 (-2.7,3.7)	1.0 (-2.1,4.4)	1.4 (-2.4,3.7)	1.7 (-0.5,6.2)
Median*	0.1	0.3	0.3	0.5	0.9	1.0	1.4	1.4
October Tealbook	-		-		-		-	

Model	Output Gap (Q4)							
	2016		2017		2018		2019	
	Dec	Sept	Dec	Sept	Dec	Sept	Dec	Sept
EDO - Board of Governors	-1.7 (-2.2,-1.2)	-1.6 (-2.3,-1.0)	-1.3 (-2.6,-0.1)	-1.2 (-2.6,0.2)	-1.0 (-2.8,0.8)	-0.9 (-2.8,1.0)	-0.7 (-2.8,1.3)	-0.7 (-2.8,1.4)
New York Fed	-1.4 (-2.8,0.0)	-1.7 (-3.0,-0.5)	-2.2 (-4.5,-0.5)	-1.8 (-4.5,0.1)	-2.0 (-5.4,0.4)	-1.6 (-5.2,1.0)	-1.7 (-5.6,1.3)	-1.3 (-5.4,1.8)
PRISM - Philadelphia Fed	-1.4 (-2.2,-0.3)	-1.4 (-2.3,-0.3)	-1.6 (-2.8,-0.3)	-1.4 (-2.4,0.2)	-1.5 (-2.9,-0.1)	-1.2 (-2.5,0.4)	-1.2 (-2.8,0.3)	-1.0 (-2.3,0.9)
Median*	-1.4	-1.6	-1.6	-1.4	-1.5	-1.2	-1.2	-1.0
October Tealbook	0.1		0.8		1.2		1.2	

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

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





Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model's forecast conditions on data through the third quarter of 2016 and on a preliminary Tealbook forecast for the fourth quarter of 2016. Average real GDP growth is 2.8 percent over the forecast horizon (2017:Q1 to 2019:Q4), which is slightly below the estimated trend growth rate of 3 percent. Inflation reaches the Committee's 2 percent objective in the third quarter of 2017 and then slightly overshoots the target, reaching almost 2.3 percent at the end of 2018 before again converging. The path for the federal funds rate slopes upward over the forecast horizon, reaching 3.6 percent by the end of 2019.

Recent data, including the nowcast for the fourth quarter of 2016, portray an economy in which unemployment is somewhat below the model's steady-state value of 5¼ percent, while consumption growth over the past few quarters has been mostly to the upside of the model's expectations. However, despite several years of what the model perceives as unusually accommodative monetary policy, both investment and inflation have been typically disappointing.

In reaction to these data, the model interprets the path of unemployment and consumption growth as signaling that its main cyclical driver, the aggregate risk premium, is roughly at steady state. The weakness of investment is then accounted for by an elevated risk premium on physical capital, while low inflation is largely attributed to markup shocks.

Consistent with this interpretation of the data, the EDO model's near-term (2017:Q1 to 2017:Q2) forecast is boosted by the positive effects of negative markup shocks. However, these effects fade rather quickly. Over the medium-term horizon, growth is restrained by the waning effects of unusually accommodative monetary policy and by the extremely persistent adverse movements in the capital-specific risk premium. As these headwinds gradually fade, GDP growth picks up again, reaching 2.9 percent at the end of 2019.

Largely in reaction to the still-low levels of the employment-to-population ratio, the model estimates an output gap of negative 1.7 percent in the fourth quarter of 2016.² With growth slightly below trend, the output gap closes very slowly and remains at negative 0.7 percent by the end of 2019. The real natural rate of interest is projected to increase from negative 0.8 percent at the end of 2016 to 1.4 percent at the end of 2019, 0.7 percentage points below its steady-state value of 2.1 percent. The natural rate is held down by the capital risk-premium shock and by the labor supply shock.

The nowcast for GDP growth in the fourth quarter of 2016 is weaker than the model would have expected in September, but the model attributes most of this unexpected weakness to transient factors that reverse rapidly in the forecast. Growth in 2017 is accordingly just a touch higher than in the previous round, with technology and markup shocks still the main contributors boosting growth. The nowcast for core inflation in the fourth quarter of 2016 is also below model expectations, with the revision explained almost entirely by more adverse markup shocks in the quarter. Although the same innovation to markups also lowers the near-term forecast for inflation, the overall forecast contour for the inflation rate over the forecast horizon remains similar to the previous round.

The FRBNY Model

The FRBNY model forecasts are obtained using data released through 2016Q3, augmented for 2016Q4 with the FRBNY staff forecasts (as of November 29) 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 2016Q4 averages up to November 29.

The model projects real GDP growth of 1.8 percent in 2016 (Q4/Q4), very little changed relative to the September forecast of 1.9 percent, and of 1.9 percent in 2017, somewhat lower than the 2.3 percent forecast in September. The growth outlook is revised slightly downward from 2.6 percent to 2.5 percent in 2018 and is expected to move to a more robust 2.7 percent in

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.

2019. By contrast, the projections of inflation are revised upward in 2016 and 2017 (Q4/Q4), to 1.8 percent and 1.4 percent, respectively. The inflation forecasts remain unchanged at 1.4 and 1.5 percent in 2018 and 2019, respectively.

Over the short term, the revisions in the forecasts largely reflect surprises in the data releases for 2016Q3 relative to the September FRBNY staff forecast for that quarter: GDP growth printed slightly lower and core PCE inflation was somewhat higher. Although there is no particular driver of less optimistic growth outlook for 2017 relative to the September forecast, the model projects that a more pronounced drag from a negative productivity shock along with less favorable aggregate demand and markup shocks were among the factors behind this outcome.

Overall, the forecast remain in line with the narrative that we have been describing in the past. The financial headwinds that slowed down the recovery were finally retreating over the course of 2014 and early 2015, pushing GDP growth above potential and the natural rate of interest back into positive territory. However, the turbulence in financial markets experienced in late 2015 and early 2016, with the associated widening of credit spreads, temporarily derailed this normalization process. More recently, this turbulence has faded and the model projects economic activity to continue to increase at a moderate pace in 2017 and to accelerate somewhat in the subsequent years. Against this positive set of fundamentals, the payback from the monetary policy stimulus put in place throughout the recovery is projected to exercise some restraint on GDP growth, slowing the pace at which the output gap will be closing over the medium term. The real natural rate of interest is expected to reach 1 percent by the end of the forecast horizon, unchanged relative to the September forecast.

The projections are surrounded by notable uncertainty. The width of the 68 percent probability interval for GDP growth is 4.9 percentage points in 2017, ranging from -0.8 to 4.1 percent, and widens to 5.6 percentage points in 2019, from -0.1 to 5.5 percent. Uncertainty for the real natural rate and the output gap is also extremely large. For 2019, the 68 percent bands for the natural rate range from -1.1 to 3 percent, while those for the output gap range from -5.6 to 1.3 percent. The 68 percent probability intervals for inflation range from 0.6 to 2.1 percent in 2017 and from 0.3 to 2.6 percent in 2019.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2016Q3 that are then supplemented with a 2016Q4 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output growth will accelerate from a 1.8 percent pace in 2016 to 3.3 percent in 2019. The nowcast pins down real output growth in 2016Q4 at 2 percent. Growth gradually accelerates to a peak of 3.3 percent in 2018Q3, and then runs at about that pace through the end of the forecast horizon. Core inflation rises from 1.8 percent in 2016Q4 to 2.2 percent at the end of 2019. The PRISM projection has the funds rate following an estimated policy rule through the forecast horizon: the federal funds rate rises to 1.1 percent in 2017Q1 and then advances steadily to reach 3.8 percent in 2019Q4.

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 0.1 percent in 2016Q4. As output growth strengthens and the economy normalizes to trend, the natural rate rises over the forecast horizon to reach about 1.4 percent at the end of 2019. Our estimates of the output gap are derived from the log deviation of real output from its flexible-price counterfactual level³. The estimated output gap is at -1.4 percent in 2016Q4 and shrinks slowly over the next three years to reach -1.2 percent at the end of 2019.

According to PRISM, negative shocks to TFP were the primary factors accounting for below-trend output growth in 2016. The strong output growth in 2016Q3 is largely attributed to positive government spending and investment shocks. But past TFP shocks are expected to exert a small drag on output growth through the forecast horizon as do monetary policy and financial shocks. By early 2018 though, output growth rises above the model-estimated trend rate. The unwinding of past investment shocks, government spending shocks, and labor supply shocks continue to make a positive contribution to output growth over the forecast horizon. Consumption growth surged in 2016Q2 driven mainly by a strong financial shock. As financial

³ Note though that PRISM does not use this construct of the output gap in its estimated policy rule but instead uses the stochastically detrended level of output.

shocks wane, consumption growth decelerates to a below-trend pace over the near term but then rebounds to trend by the end of 2018. Investment growth is running at a pace that is close to the model's trend pace at the end of 2016 and then largely maintains that pace through the forecast horizon. 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 2016Q4 nowcast for core PCE inflation is 1.8 percent. The model predicts that inflation rises to about 2 percent in 2017Q1 and then edges up to 2.2 percent by the end of 2019. With inflation running at about trend over the next three years, PRISM has upward pressure on prices from past investment shocks and 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 2017Q1 the funds rate averages 1.1 percent and rises to 2.5 percent by the end of 2017 – a slightly slower pace of normalization compared to the September forecast. By the end of 2019, PRISM has the federal funds rate at 3.8 percent. 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.