BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

FOMC SECRETARIAT

Date: March 3, 2017

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 3, 2017

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[1]We thank Kirstin Hubrich and Keith Sill for their contributions, and Abhi Gupta and Pearl Li for their assistance.

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 2016Q4 and conditioning assumptions or "nowcasts" for 2017Q1 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 January 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 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 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, across all three models the projections are weaker than they were in December. The median forecast has growth equal to 2.5, 2.3, and 2.6 percent in 2017, 2018, and 2019, respectively, down from 2.7, 2.7, and 2.9 percent in December. Disagreement across output growth forecasts, defined as the difference between the highest and lowest forecast, has not changed significantly relative to December. On the low end, FRBNY has output growth at 1.9 percent in 2017, rising to 2.5 percent in 2019. On the high end, PRISM has output growth at 2.5 percent in 2017, rising to 3.3 percent in 2019. The Tealbook forecast continues to be on balance weaker than the three models' projections with a growth path that decelerates from 2.1 percent in 2017 to 1.8 percent in 2019.

Turning to inflation, the projections are stronger than in December for EDO and FRBNY, while for PRISM they are slightly weaker. The disagreement in inflation projections among models is similar to December. FRBNY displays a forecast for core PCE inflation which is essentially flat at 1.6 percent through the forecasting horizon. In contrast, PRISM predicts that inflation will be back to about 2 percent in 2017 and remain there through 2019. EDO projects the strongest inflation path, with inflation at 2.3 percent through the forecasting horizon, therefore slightly overshooting the Committee's longer-run objective. Both EDO and PRISM project a stronger inflation path than does the January Tealbook, while FRBNY continues to foresee a weaker path than the January Tealbook.

The three models continue to show similar assessments of the current level and the future expected evolution of both the real natural rate of interest and the output gap. Looking at the medians across the three models' point forecasts, the real natural rate is projected to turn positive at the end of 2017 and to rise gradually to 1.4 percent in 2019, with a fairly narrow range of 1.1 to 1.6 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 output gap estimates are slightly more optimistic than they were in December. 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 and EDO forecasts are very similar, with the funds rate reaching 2.0 and 2.1

percent respectively at the end of 2017, and then climbing to 3.7 percent by the end of 2019. FRBNY continues to expect a more gradual pace of tightening with the federal funds rate at 1.6 percent at the end of 2017 and 2.8 percent at the end of 2019. The January Tealbook forecasts the federal funds rates to be 1.5 percent at the end of 2017, close to the FRBNY projection. However, its pace of normalization is steeper afterwards, with the federal funds rate reaching 3.4 percent in 2019 and therefore catching up with the projections from EDO and PRISM.

Forecasts

Model	Real GDP Growth (Q4/Q4)					
	2017		2018		2019	
	Mar	*Dec*	**Mar**	*Dec*	**Mar**	*Dec*
EDO - Board of Governors	**2.6** **(1.1,4.2)**	2.8 (0.9,4.7)	**2.3** **(0.3,4.5)**	2.7 (0.6,4.8)	**2.6** **(0.4,4.6)**	2.9 (0.7,5.0)
FRBNY - New York Fed	**1.9** **(-0.2,3.7)**	1.9 (-0.8,4.1)	**2.2** **(-0.6,4.7)**	2.5 (-0.3,5.1)	**2.5** **(-0.3,5.2)**	2.7 (-0.1,5.5)
PRISM - Philadelphia Fed	**2.5** **(0.4,4.8)**	2.7 (-0.2,5.8)	**3.1** **(-0.2,6.7)**	3.2 (-0.2,6.7)	**3.3** **(-0.2,7.0)**	3.3 (-0.1,7.1)
Median*	**2.5**	2.7	**2.3**	2.7	**2.6**	2.9
January Tealbook	**2.1**		**2.0**		**1.8**	

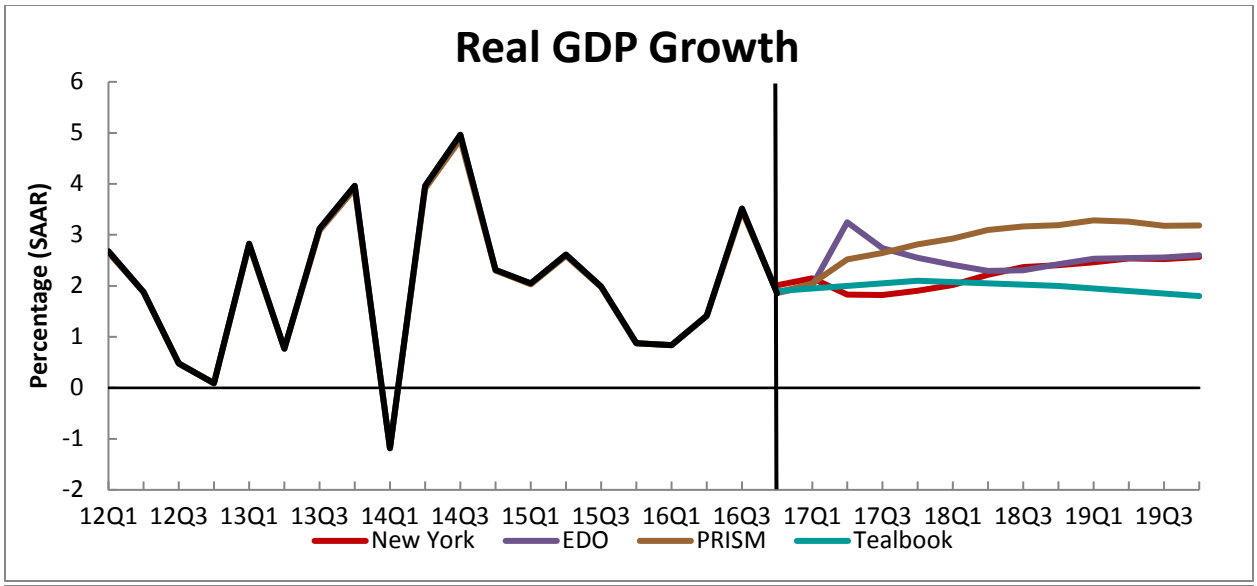
Model	Core PCE Inflation (Q4/Q4)					
	2017		2018		2019	
	Mar	*Dec*	**Mar**	*Dec*	**Mar**	*Dec*
EDO - Board of Governors	**2.3** **(1.8,2.8)**	2.0 (1.4,2.6)	**2.3** **(1.5,3.2)**	2.2 (1.4,3.1)	**2.3** **(1.4,3.3)**	2.2 (1.3,3.2)
FRBNY - New York Fed	**1.6** **(1.0,2.1)**	1.4 (0.6,2.1)	**1.5** **(0.5,2.4)**	1.4 (0.4,2.3)	**1.6** **(0.4,2.7)**	1.5 (0.3,2.6)
PRISM - Philadelphia Fed	**1.9** **(1.1,2.8)**	2.0 (0.9,3.3)	**2.0** **(0.5,3.6)**	2.1 (0.5,3.6)	**2.1** **(0.4,3.7)**	2.2 (0.6,3.9)
Median*	**1.9**	2.0	**2.0**	2.1	**2.1**	2.2
January Tealbook	**1.7**		**1.9**		**2.0**	

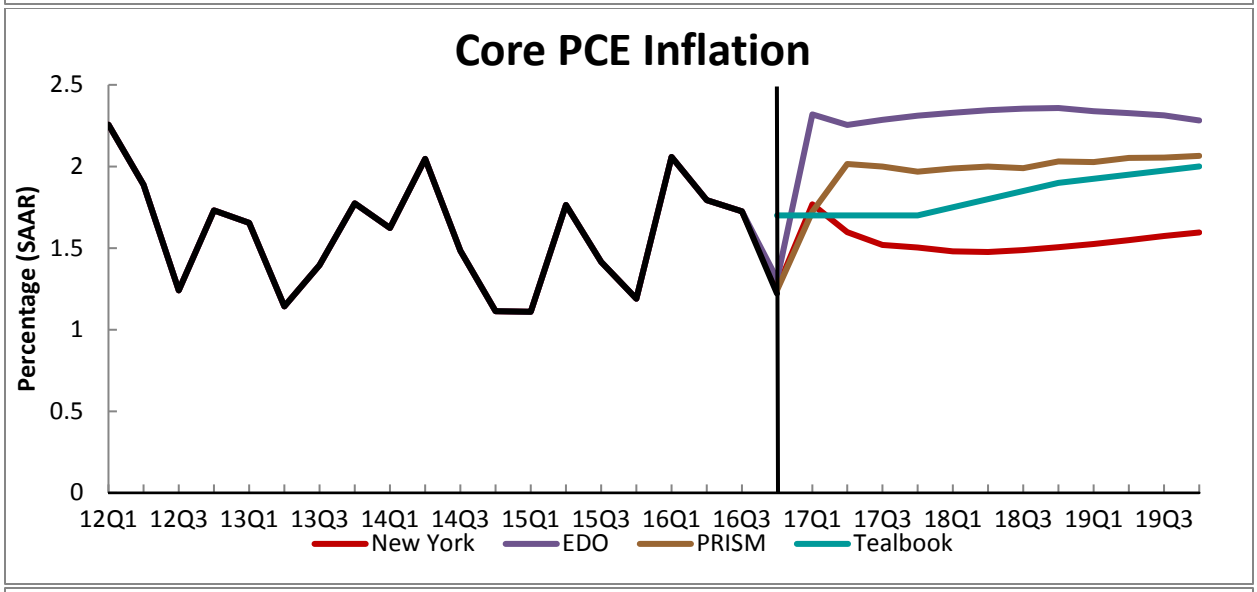
Model	Federal Funds Rate (Q4)					
	2017		2018		2019	
	Mar	*Dec*	**Mar**	*Dec*	**Mar**	*Dec*
EDO - Board of Governors	**2.1** **(1.1,3.1)**	2.0 (0.8,3.2)	**3.1** **(1.5,4.8)**	3.0 (1.3,4.8)	**3.7** **(1.8,5.6)**	3.6 (1.7,5.5)
New York Fed	**1.6** **(0.5,2.9)**	1.4 (0.3,2.9)	**2.4** **(0.9,4.1)**	2.2 (0.7,4.0)	**2.8** **(1.0,4.7)**	2.7 (0.9,4.6)
PRISM - Philadelphia Fed	**2.0** **(0.9,3.3)**	2.5 (1.1,3.9)	**3.2** **(0.8,5.1)**	3.4 (0.9,5.5)	**3.7** **(1.2,6.5)**	3.8 (1.0,6.6)
Median*	**2.0**	2.0	**3.1**	3.0	**3.7**	3.6
January Tealbook	**1.5**		**2.5**		**3.4**	

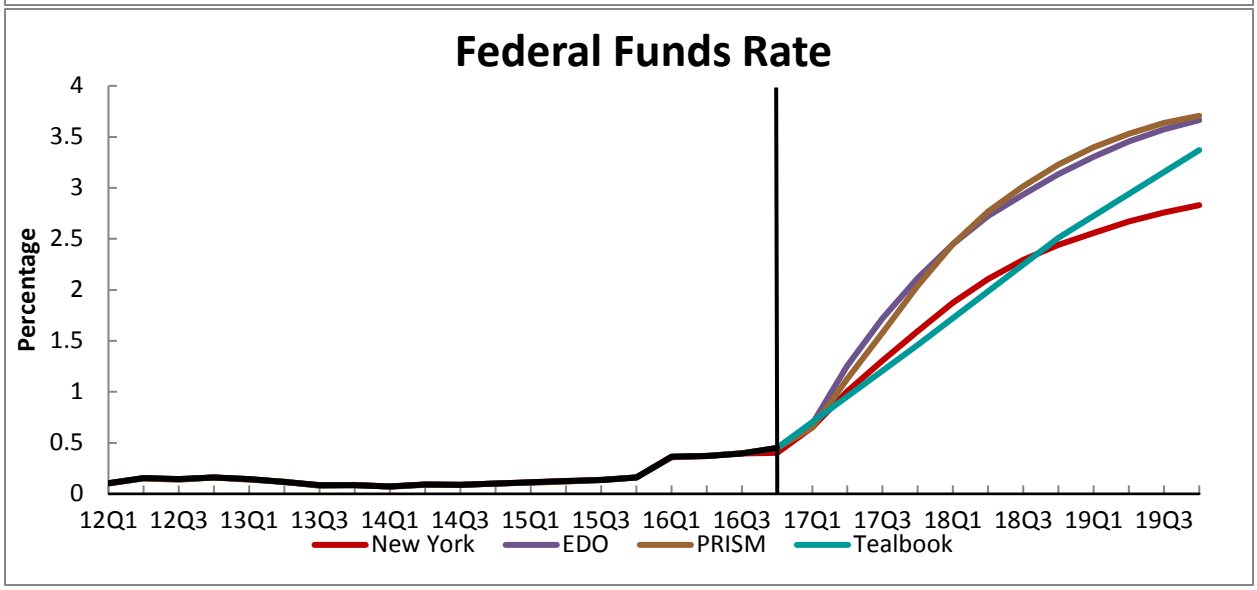
Model	Real Natural Rate of Interest r* (Q4)					
	2017		2018		2019	
	Mar	*Dec*	**Mar**	*Dec*	**Mar**	*Dec*
EDO - Board of Governors	**0.8** **(-4.1,5.6)**	0.8 (-4.0,5.5)	**1.4** **(-3.6,6.5)**	1.2 (-3.8,6.3)	**1.6** **(-3.4,6.8)**	1.4 (-3.7,6.3)
New York Fed	**0.4** **(-1.2,2.0)**	0.3 (-1.4,2.1)	**0.8** **(-1.0,2.5)**	0.7 (-1.3,2.6)	**1.1** **(-0.8,2.9)**	1.0 (-1.1,3.0)
PRISM - Philadelphia Fed	**0.0** **(-2.8,3.2)**	0.2 (-3.0,3.4)	**1.0** **(-2.3,4.2)**	0.9 (-2.7,3.7)	**1.4** **(-1.8,4.4)**	1.4 (-2.4,3.7)
Median*	**0.4**	0.3	**1.0**	0.9	**1.4**	1.4
January Tealbook	-		-		-	

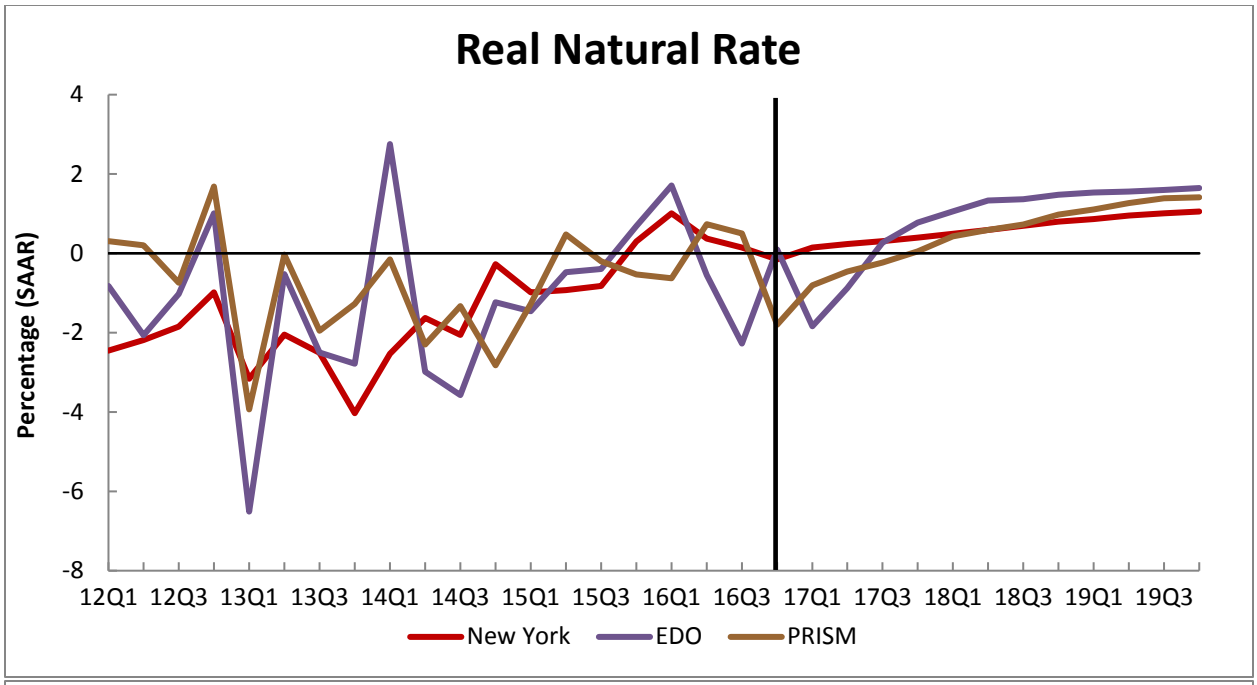
Model	Output Gap (Q4)					
	2017		2018		2019	
	Mar	*Dec*	**Mar**	*Dec*	**Mar**	*Dec*
EDO - Board of Governors	**-1.0** **(-2.1,0.0)**	-1.3 (-2.6,-0.1)	**-0.9** **(-2.6,0.8)**	-1.0 (-2.8,0.8)	**-0.7** **(-2.8,1.3)**	-0.7 (-2.8,1.3)
New York Fed	**-1.5** **(-3.3,0.0)**	-2.2 (-4.5,-0.5)	**-1.5** **(-4.4,0.8)**	-2.0 (-5.4,0.4)	**-1.3** **(-4.9,1.6)**	-1.7 (-5.6,1.3)
PRISM - Philadelphia Fed	**-1.4** **(-2.4,0.1)**	-1.6 (-2.8,-0.3)	**-1.4** **(-2.4,0.2)**	-1.5 (-2.9,-0.1)	**-1.2** **(-2.4,0.6)**	-1.2 (-2.8,0.3)
Median*	**-1.4**	-1.6	**-1.4**	-1.5	**-1.2**	-1.2
January Tealbook	**1.1**		**1.5**		**1.7**	

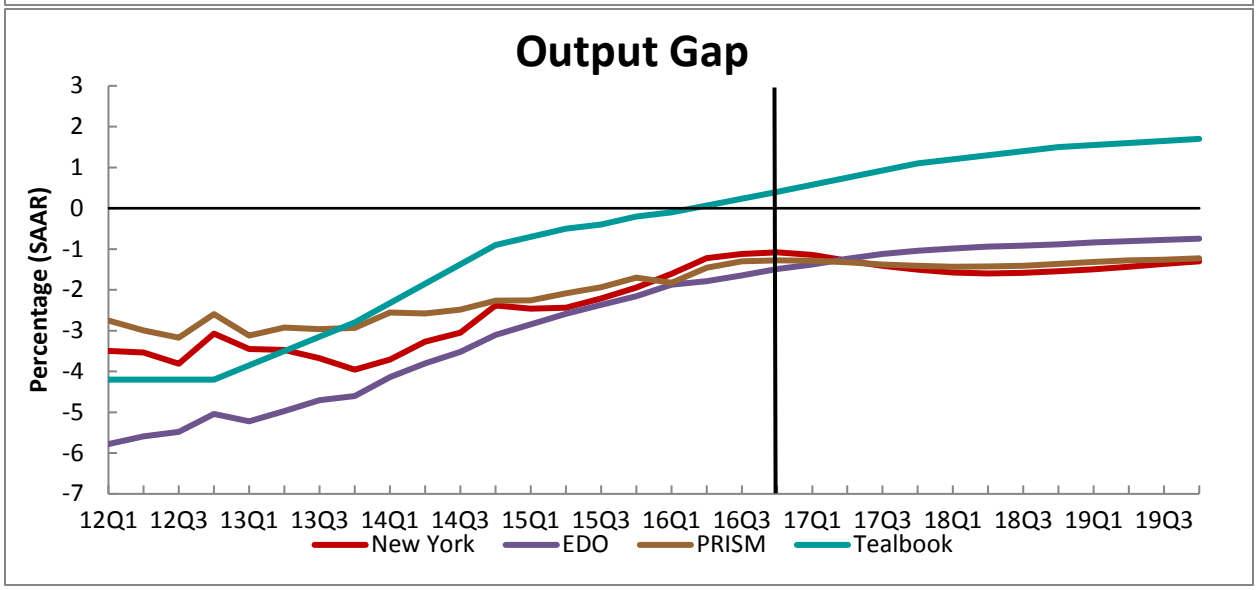
For each individual forecast, the numbers in parentheses represent 68% confidence bands.
*The median forecast is calculated as the median of the Q4/Q4 projections from the forecasters.


Real GDP Growth
Percentage (SAAR)
6
5
4
3
2
1
0
-1
-2
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3
New York
EDO
PRISM
Tealbook


Core PCE Inflation
Percentage (SAAR)
2.5
2
1.5
1
0.5
0
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3
New York
EDO
PRISM
Tealbook


Federal Funds Rate
Percentage
4
3.5
3
2.5
2
1.5
1
0.5
0
12Q1 12Q3 13Q1 13Q3 14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3
New York
EDO
PRISM
Tealbook





Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model's forecast is conditional on data through the fourth quarter of 2016 and on a preliminary Tealbook forecast for the first quarter of 2017. Average real GDP growth is 2.6 percent over the forecast horizon (2017Q2 to 2019Q4), somewhat below the estimated trend growth rate of 3 percent. Inflation slightly overshoots the Committee's 2 percent objective starting in the first quarter of 2017, staying around 2.3 percent over the forecast horizon. The path for the federal funds rate slopes upward over the forecast horizon, reaching 3.7 percent by the end of 2019.

Recent data, including the nowcast for the first quarter of 2017, 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. Despite several years of what the model perceives as unusually accommodative monetary policy, both investment and inflation have been below trend, although inflation has rebounded since the beginning of 2017.

In reaction to these data, the model interprets the recent path of unemployment and consumption growth as signaling that its main cyclical driver, the aggregate risk premium, is just below its steady state. The weakness of investment is then accounted for by an elevated risk premium on physical capital. Until recently inflation has been below target largely due to negative markup shocks. The overshooting of the inflation forecast reflects the abating of such shocks.

Consistent with this interpretation of the data, the EDO model's near-term (2017Q2 to 2017Q3) growth forecast is boosted by the positive effects of negative aggregate risk premium 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 2.6 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 1.4 percent in the first quarter of 2017.[2] 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 1.8 percent in the first quarter of 2017 to 1.6 percent at the end of 2019, ½ percentage points below its steady-state value of 2.1 percent. The natural rate is held down mainly by the capital risk-premium shock.

The nowcast for GDP growth in the first quarter of 2017 is considerably weaker than the model expected in December, but the model attributes most of this unexpected weakness to transient factors that reverse rapidly in the forecast.[3] Growth in 2017 is accordingly just a touch lower than in the previous round, with capital risk-premium shocks as the main contributor to restraining growth. The nowcast for core inflation in the first quarter of 2017 is above model expectations, with the revision explained almost entirely by less adverse markup shocks in the current quarter. However, adverse markup shocks continue to restrain the near-term forecast, while the medium-term forecast contour for the inflation rate remains similar to the previous round.

The FRBNY Model

The FRBNY model forecasts are obtained using data released through 2016Q4, augmented for 2017Q1 with the FRBNY staff forecasts (as of February 28) 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 February 28.

The model projects real GDP growth of 1.9, 2.2, and 2.5 percent (Q4/Q4) in 2017, 2018, and 2019, respectively. While the 2017 projections are unchanged relative to December, the medium and longer run forecasts are slightly weaker than in December. By contrast, the projections of inflation are revised upward throughout the horizon. These forecasts are 1.6, 1.5, and 1.6 for 2017, 2018, and 2019, respectively, up from 1.4, 1.4, and 1.5, respectively, 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.

[3] Note that the nowcast taken on board in the December EDO model's forecast was a preliminary nowcast that was revised in the final December Tealbook projection.

December. The projections are surrounded by notable uncertainty. The range of 68 percent probability interval for GDP growth is as large as 3.9 percentage points in 2017, from -0.2 to 3.7 percent, and widens over the forecast horizon, reaching 5.6 percentage points in 2020, from -0.3 to 5.3 percent. The 68 percent probability intervals for inflation range from 1.0 to 2.1 percent in 2017 and from 0.4 to 2.9 percent in 2020.

The revisions in the forecasts reflect the fact that the December FRBNY staff forecast for 2017Q1 core PCE inflation is much higher than what the model projected in December, while real GDP growth is slightly lower. In a broader sense, these revisions are the result of two contrasting forces. On the one hand corporate spreads narrowed since November, possibly because of the post-election increase in confidence triggering a decrease in the safety premium. This decrease in spreads translated in an increase in the real natural rate of interest, whose projected path is about 10 basis points higher than in December, and resulted in higher forecasts for inflation and output growth. On the other hand, the model's assessment of productivity growth has worsened since December, leading to lower natural output and to a closing of the output gap, but also to lower output growth projections.

Finally, the projected path for the federal funds rate is slightly steeper than in December, following the higher path of inflation. It is broadly in line with the January Tealbook forecasts until mid-2018 and shallower afterwards.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2016Q4 that are then supplemented with a 2017Q1 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output growth will accelerate from a 1.9 percent pace in 2016 to 3.3 percent in 2019. The nowcast pins down real output growth in 2017Q1 at 2 percent. Growth gradually accelerates to a peak of about 3.3 percent in 2019Q1. Core inflation rises from 1.7 percent in 2017Q1 to 2.1 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 2 percent in 2017Q4 and then advances steadily to reach 3.7 percent in 2019Q4.

We also forecast the natural rate of interest and the output gap as determined from the model. The natural rate of interest is estimated at -0.8 percent in 2017Q1. 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 level. The estimated output gap is at -1.3 percent in 2017Q1 and shrinks slowly over the next three years to reach -1.2 percent at the end of 2019.

According to PRISM, below-trend output growth in 2016 was largely due to negative shocks to TFP and the discount rate (financial shocks). Output growth briefly surged in 2016Q3 due to positive government spending and investment shocks that were not offset by other shocks in the model. Going forward, TFP shocks exert a small drag on output growth through the forecast horizon as do monetary policy and financial shocks. By mid-2018, 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. In more detail, consumption growth ran at a healthy pace in 2016 driven by strong contributions from financial shocks. In the model, financial shocks account for the discrepancy between strong consumption growth and weak investment growth. As financial shocks wane, consumption growth decelerates over the near term but then rebounds to trend by the end of 2018. Shocks to the marginal efficiency of investment led to strong investment growth in 2016Q4. As these shocks wane, investment growth runs at a slightly above-trend pace in 2017Q1 but then reverts to trend over the remainder of the forecast horizon. On balance, the model continues to imply a detrended level of output that is below its steady state. 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 2017Q1 nowcast for core PCE inflation is 1.7 percent. The model predicts that inflation rises to 2 percent in 2017Q2 and then runs at about that pace through the end of 2019. With inflation running at trend over the next three years, PRISM has upward pressure on prices from investment growth 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 a rule-based federal funds rate path going forward. By 2017Q4 the funds rate averages 2 percent, rising to 3.2 percent in 2018Q4 and 3.7 percent in

2019Q4 – a slightly slower pace of normalization compared to the December 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.