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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 2016Q2 and conditioning assumptions or "nowcasts" for 2016Q3 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, and it is no longer constrained to be consistent with market expectations. For the sake of comparison, the tables include the July 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 June 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.

The first notable feature of this round of forecasts is that the three models display an unusually low level of disagreement regarding the prospects for GDP growth. All models expect output growth to rebound in the second half of 2016 and to settle somewhat below 3 percent in 2017 to 2019. These projections are more optimistic than they were in June for 2017, but not much changed for 2018. They are also stronger than those in the July Tealbook, a difference that has persisted over the past several forecast rounds, although it is now less pronounced than it was last year.

Turning to inflation, the disagreement among models is slightly more pronounced than for GDP growth, although not much changed from June. In FRBNY, the return of core PCE inflation to mandate consistent levels proceeds 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. These two models' inflation forecasts are now a bit lower than they were at the beginning of the summer, but they remain stronger than the Tealbook's.

As it is the case for their GDP forecasts, the three models also essentially agree on their assessment of the current level and the future expected evolution of both r* and the output gap. This agreement is especially remarkable given the uncertainty inherent in the estimation of these unobservable variables, which is well reflected in their wide posterior probability intervals. 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 1½ percent in 2018, with a narrow range between 1 and 1.7 percent across the three models. As for the output gap, all models estimate it to be currently negative and to remain so throughout the forecast horizon, even if their estimates are slightly less pessimistic than they were in June. This assessment of the amount of slack still present in the economy is in contrast with that of the Tealbook, whose output gap estimate hews more closely to the signal coming from unemployment and it is hence seen to be 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.

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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 1.1 percent at the end of 2016, and then climbing to 4 percent by the end of 2018. EDO projects a somewhat shallower path, reaching 3.7 percent at the end of 2018, while FRBNY expects a tightening pace of less than 1 percentage point per year in 2017 and 2018, and even less in 2019, very close to that assumed in the July Tealbook.

Forecasts

Model	Real GDP Growth (Q4/Q4)						
	2016		**2017**		**2018**		**2019**
	September	*June*	**September**	*June*	**September**	*June*	**September**
EDO - Board of Governors	**2.0** **(1.3,2.6)**	2.1 (1.0,3.2)	**2.7** **(0.7,4.8)**	2.3 (0.3,4.4)	**2.7** **(0.6,4.8)**	2.6 (0.4,4.7)	**2.9** **(0.8,5.0)**
FRBNY - New York Fed	**1.9** **(1.0,2.6)**	1.6 (0.0,2.8)	**2.3** **(-0.7,4.6)**	2.2 (-0.9,4.6)	**2.6** **(-0.3,5.2)**	2.5 (-0.3,5.2)	**2.7** **(-0.2,5.5)**
PRISM - Philadelphia Fed	**2.1** **(1.5,2.8)**	2.1 (0.6,3.5)	**2.9** **(-0.2,6.2)**	3.0 (-0.2,6.6)	**3.2** **(-0.0,7.0)**	3.4 (-0.1,7.1)	**3.2** **(-0.3,6.9)**
Median*	**2.0**	2.1	**2.7**	2.3	**2.7**	2.6	**2.9**
July Tealbook	**1.7**		**2.5**		**2.1**		

Model	Core PCE Inflation (Q4/Q4)						
	2016		**2017**		**2018**		**2019**
	September	*June*	**September**	*June*	**September**	*June*	**September**
EDO - Board of Governors	**1.7** **(1.5,1.8)**	2.0 (1.6,2.3)	**2.1** **(1.3,2.8)**	2.3 (1.5,3.1)	**2.3** **(1.3,3.2)**	2.4 (1.4,3.3)	**2.2** **(1.2,3.2)**
FRBNY - New York Fed	**1.6** **(1.4,1.8)**	1.6 (1.2,1.9)	**1.3** **(0.5,2.1)**	1.2 (0.3,2.1)	**1.4** **(0.3,2.4)**	1.3 (0.2,2.4)	**1.5** **(0.3,2.7)**
PRISM - Philadelphia Fed	**1.9** **(1.6,2.2)**	1.9 (1.4,2.4)	**2.0** **(0.7,3.3)**	2.0 (0.5,3.5)	**2.1** **(0.5,3.7)**	2.1 (0.4,3.8)	**2.2** **(0.4,3.8)**
Median*	**1.7**	1.9	**2.0**	2.0	**2.1**	2.1	**2.2**
July Tealbook	**1.6**		**1.6**		**1.8**		

Model	Federal Funds Rate (Q4)						
	2016		**2017**		**2018**		**2019**
	September	*June*	**September**	*June*	**September**	*June*	**September**
EDO - Board of Governors	**0.8** **(0.3,1.3)**	1.2 (0.5,2.1)	**2.3** **(0.9,3.6)**	2.4 (1.0,4.0)	**3.2** **(1.4,5.0)**	3.2 (1.3,5.1)	**3.7** **(1.7,5.6)**
New York Fed	**0.6** **(0.1,1.4)**	0.6 (0.1,1.7)	**1.5** **(0.3,3.1)**	1.4 (0.3,3.1)	**2.2** **(0.7,4.1)**	2.2 (0.6,4.1)	**2.7** **(0.9,4.7)**
PRISM - Philadelphia Fed	**1.1** **(0.5,1.6)**	1.6 (0.7,2.5)	**2.8** **(1.1,4.5)**	3.0 (1.2,5.1)	**3.6** **(1.2,6.1)**	3.6 (0.8,6.1)	**4.0** **(0.9,6.4)**
Median*	**0.8**	1.2	**2.3**	2.4	**3.1**	3.2	**3.7**
July Tealbook	**0.7**		**1.5**		**2.5**		

Model	Real Natural Rate of Interest r* (Q4)						
	2016		2017		2018		2019
	September	*June*	September	*June*	September	*June*	September
EDO - Board of Governors	**-0.2** **(-4.3,4.0)**	0.0 (-4.6,4.6)	**0.9** **(-3.8,5.6)**	0.9 (-4.0,6.0)	**1.4** **(-3.6,6.4)**	1.3 (-3.9,6.3)	**1.4** **(-3.7,6.6)**
New York Fed	**0.3** **(-1.2,1.7)**	0.1 (-1.5,1.6)	**0.4** **(-1.4,2.2)**	0.3 (-1.4,2.1)	**0.7** **(-1.2,2.7)**	0.7 (-1.2,2.5)	**1.0** **(-1.0,3.0)**
PRISM - Philadelphia Fed	**0.3** **(-2.7,2.6)**	0.4 (-2.2,3.4)	**0.5** **(-2.6,3.4)**	0.3 (-2.5,3.5)	**1.0** **(-2.1,4.4)**	1.4 (-1.8,4.1)	**1.7** **(-0.5,6.2)**
Median*	**0.3**	0.1	**0.5**	0.3	**1.0**	1.3	**1.4**
July Tealbook	-		-		-		

| Model	Output Gap (Q4)						
	2016		2017		2018		2019
	September	*June*	September	*June*	September	*June*	September
EDO - Board of Governors	**-1.6** **(-2.3,-1.0)**	-1.5 (-2.4,-0.7)	**-1.2** **(-2.6,0.2)**	-1.4 (-3.0,0.2)	**-0.9** **(-2.8,1.0)**	-1.2 (-3.2,0.8)	**-0.7** **(-2.8,1.4)**
New York Fed	**-1.7** **(-3.0,-0.5)**	-1.8 (-3.5,-0.6)	**-1.8** **(-4.5,0.1)**	-2.0 (-5.2,0.0)	**-1.6** **(-5.2,1.0)**	-1.9 (-5.9,0.7)	**-1.3** **(-5.4,1.8)**
PRISM - Philadelphia Fed	**-1.4** **(-2.3,-0.3)**	-1.8 (-2.9,-0.5)	**-1.4** **(-2.4,0.2)**	-1.9 (-3.2,-0.4)	**-1.2** **(-2.5,0.4)**	-1.5 (-2.8,0.3)	**-1.0** **(-2.3,0.9)**
Median*	**-1.6**	-1.8	**-1.4**	-1.9	**-1.2**	-1.5	**-1.0**
July Tealbook	0.1		1.0		1.4		

For each individual forecast, the numbers in parentheses represent 68% confidence bands except for Tealbook which uses 70%.
*The median forecast is calculated as the median of the Q4/Q4 projections from the forecasters.

Real GDP Growth

Core PCE Inflation

Federal Funds Rate

Real Natural Rate

Output Gap
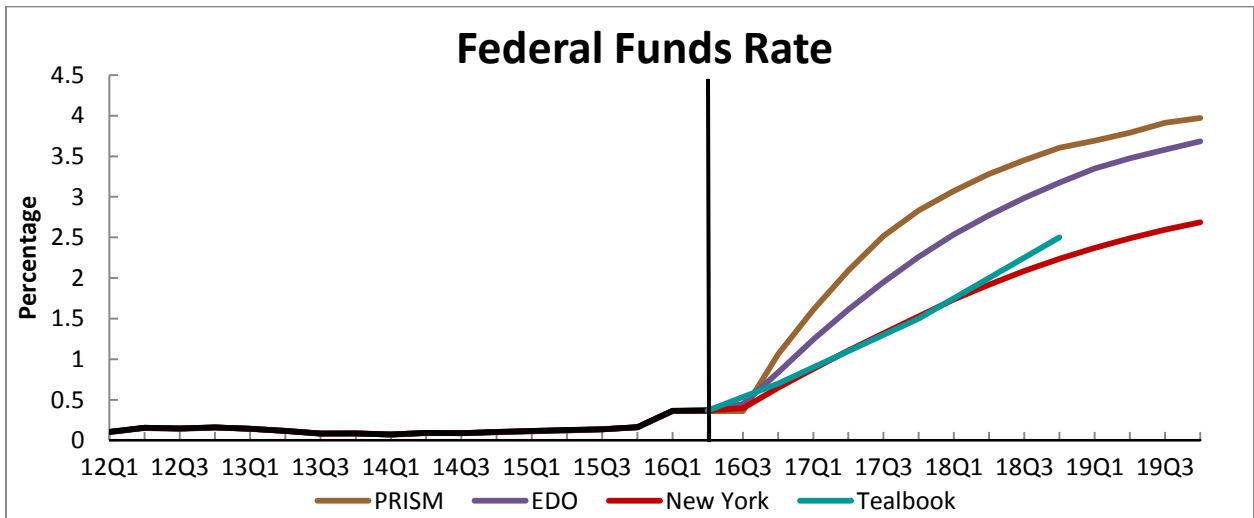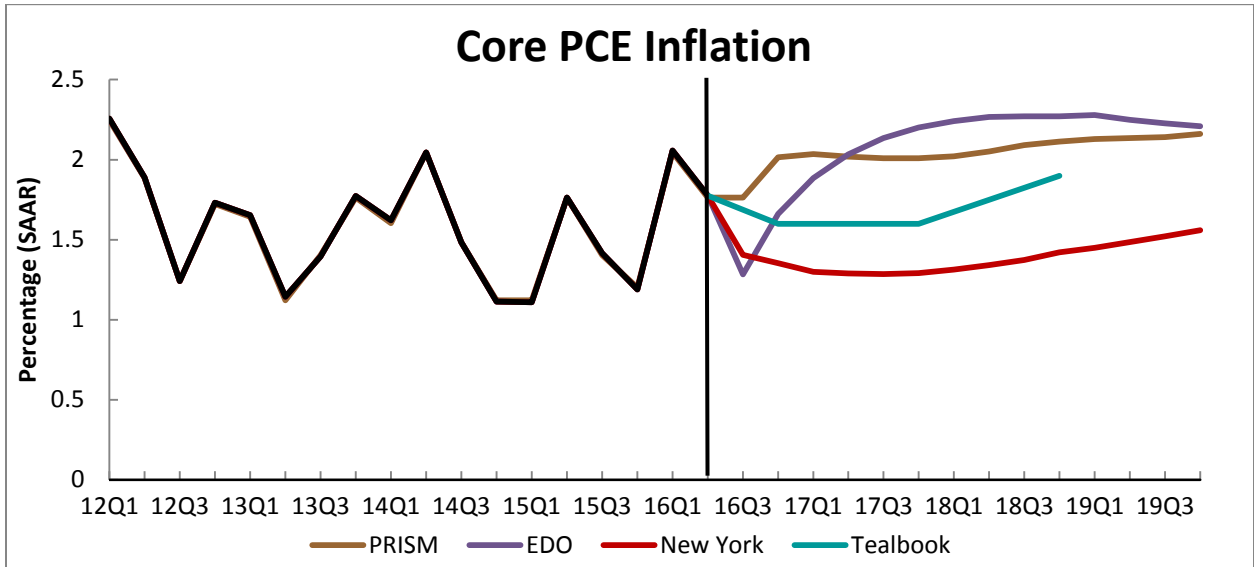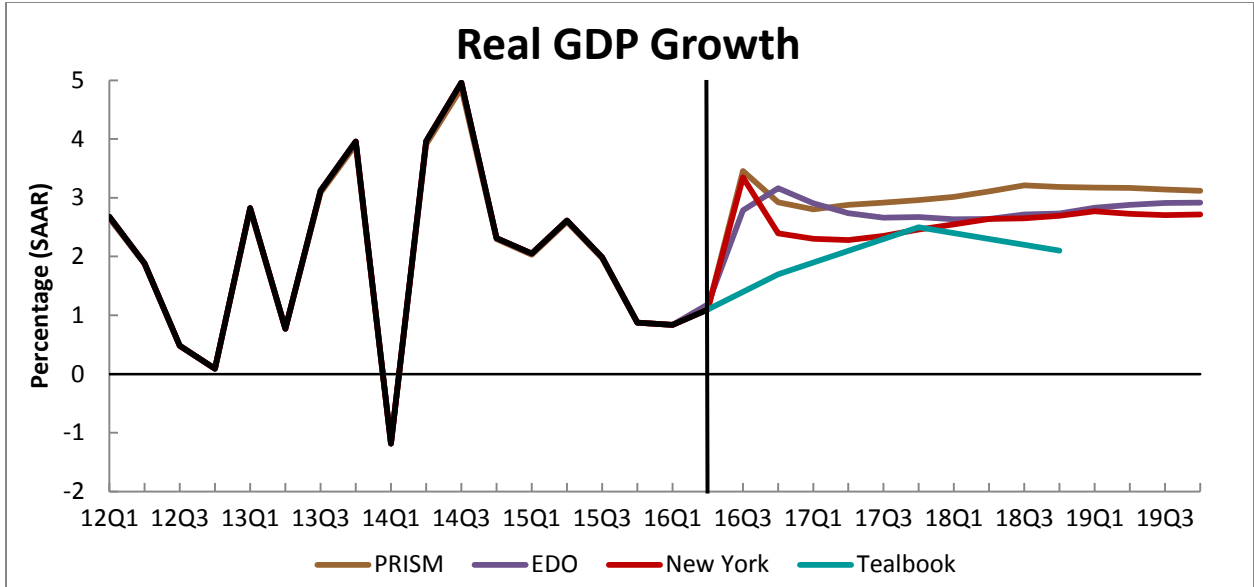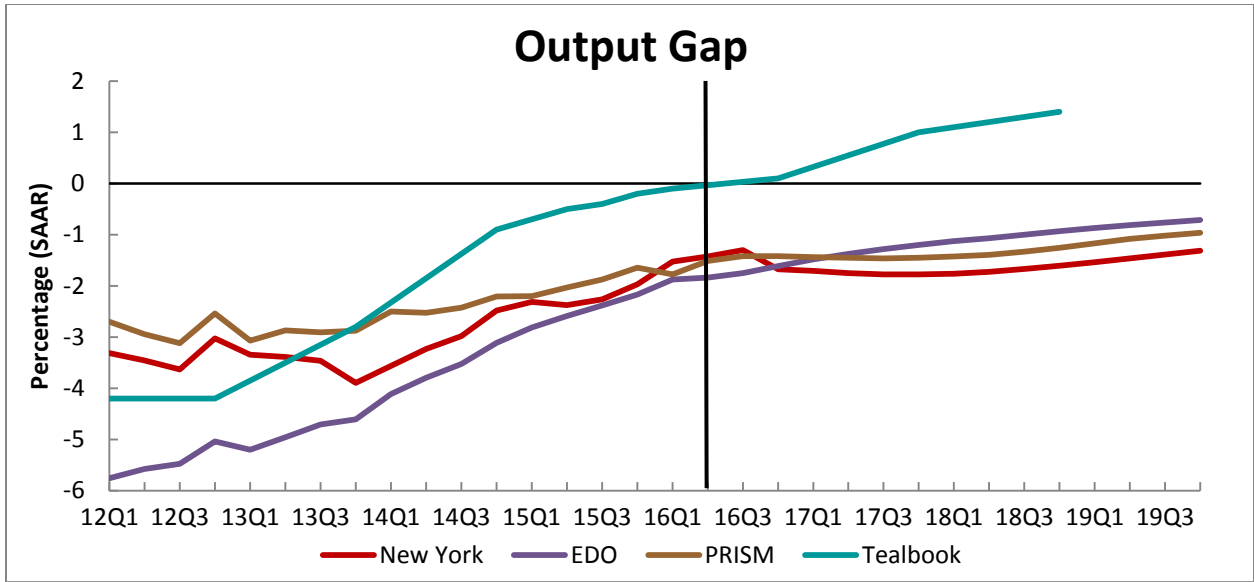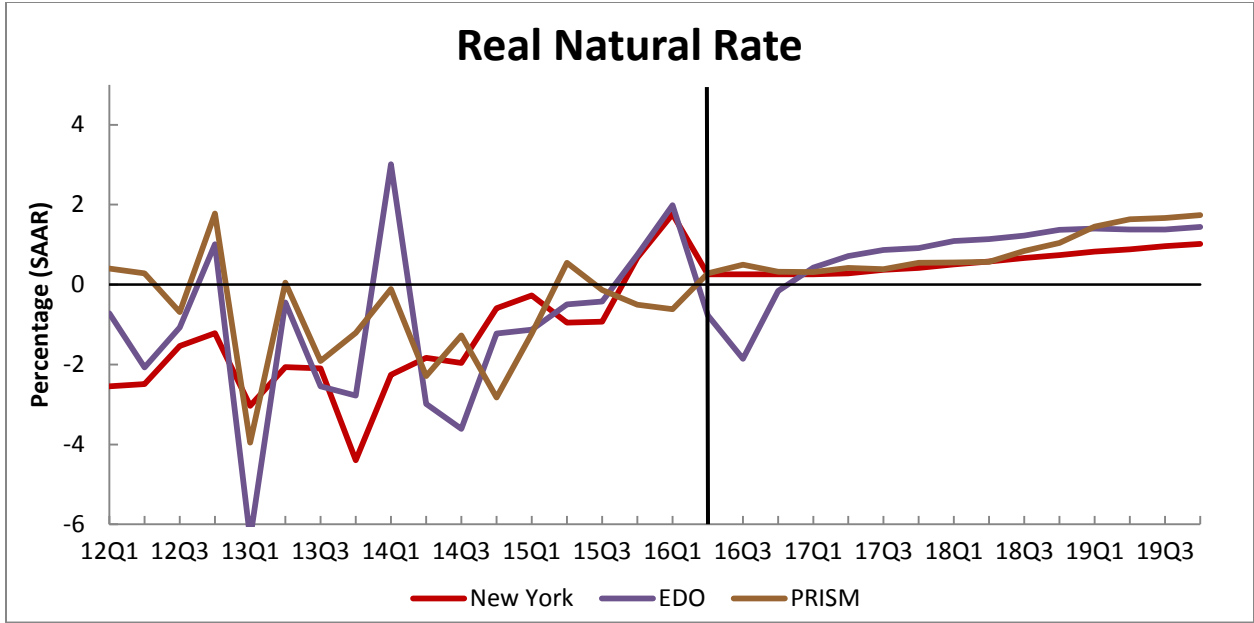
Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model forecast conditions on data through 2016:Q2 and a preliminary Tealbook forecast for the third quarter of 2016. Average real GDP growth is 2.8 percent over the forecast horizon (2016:Q4-2019:Q4), which is slightly below the estimated trend growth rate of 3 percent. Inflation reaches the Committee's 2 percent objective in the second quarter of 2017 and then slightly overshoots the target, reaching 2.3 percent in 2019:Q1 before converging again. The path for the federal funds rate is upward-sloping over the forecast horizon, reaching 3.7 percent by the end of 2019.

Recent data, including the 2016:Q3 nowcast, portray an economy in which unemployment is somewhat below the model's steady-state value of 5¼, while consumption growth over the last few quarters has been consistently to the upside of the model's expectations. On the other hand, however, despite several years of what the model perceives as unusually accommodative monetary policy, both investment and inflation have been severely 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 slightly below 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 mark-up shocks.

Consistent with this interpretation of the data, the EDO model's near-term (2016:Q4-2017:Q1) forecast is boosted by the positive effects of a low economy-wide risk premium and negative markup shocks. However, these factors fade away rather quickly. Over the medium-term, growth is restrained by the extremely persistent adverse movements in the capital-specific risk premium, as well as by the waning effects of unusually accommodative monetary policy. As these headwinds fade gradually, GDP growth picks up again, reaching 2.9 at the end of 2019.

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:Q3.[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 0.2 percent at the end of 2016 to 1.4 percent at the end of 2019, 0.7 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 the labor supply shock.

The nowcast for 2016:Q3 GDP growth is about the same as the model expected in June, while the nowcast for 2016:Q3 core inflation is much weaker at 1.3 percent. With the negative influence of the capital-specific risk premium shock dominating the positive influence of the markup shock, the model forecast for GDP growth in 2016 is slightly weaker than in June. However, growth is stronger in 2017 as the contributions of technology and markup shocks now boost growth, instead of restraining it, as they did in June. While markup shocks lower the near-term forecast for inflation substantially, this temporary factor subsides rather quickly and the overall forecast contour for the inflation rate over the forecast horizon remains similar to the previous forecast.

The FRBNY Model

The FRBNY model forecasts are obtained using data released through 2016Q2, augmented for 2016Q3 with the FRBNY staff forecasts (as of August 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 2016Q3 averages up to August 29.

Overall, the model's forecasts are somewhat more optimistic than in June: both GDP growth and inflation are marginally higher over the forecast horizon, with no significant change in the projected path of the federal funds rate. Compared to a year ago in September 2015, the FRBNY-DSGE forecast for GDP growth is very similar, with inflation a bit stronger, but the path of the policy rate is shallower in response to the renewed headwinds that have been slowing

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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.

the economy since late 2015. Matching this improvement in the outlook, the output gap is estimated to be smaller in 2016 and to close a bit more rapidly over the course of the forecast horizon than expected in June, with a slightly higher real natural rate of interest.

This moderately more optimistic outlook is consistent with the narrative that we have been describing for some time. 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 activity to pick up over the rest of 2016 and to accelerate modestly 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.

More specifically, the model projects real GDP growth of 1.9 percent in 2016 (Q4/Q4), somewhat higher than the 1.6 percent forecast in June, rising to 2.7 percent in 2019. The projections of inflation, which are unchanged at 1.6 percent in 2016, are marginally higher for 2017 and 2018 at 1.3 and 1.4 percent respectively.

For 2016, the positive revision in the growth forecast since June mostly reflects an upgrade of the FRBNY staff nowcast used in the conditioning, which brought the staff's judgmental assessment closer to the model's unconditional forecast. In fact, the model's unconditional forecast for 2016 is now less optimistic than in June (1.7 vs. 2.2 percent), and also somewhat weaker than the staff forecast. In contrast, the effect of the conditioning on inflation is minor.

The projections are surrounded by notable uncertainty, especially regarding GDP growth, with essentially no change since June, except for 2016, where we have the benefit of one more quarter of data. The exceptions are the output gap and natural rate estimates, which continue to display significant uncertainty even for 2016, since these variables are unobservable.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2016Q2 that are then supplemented with a 2016Q3 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output growth will accelerate from a 2.1 percent pace in 2016 to 3.2 percent in 2019. The nowcast pins down real output growth in 2016Q3 at 3.5 percent. Growth decelerates to 2.9 percent in 2016Q4 and then runs at about that pace through 2017 before edging up to about a 3.2 percent pace in 2018 and 2019. Core inflation remains contained and rises gradually to a 2.2 percent rate by 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 2016Q4 and then advances steadily to reach 4 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 0.5 percent in 2016Q3. As output growth strengthens and the economy normalizes to trend, the natural rate rises over the forecast horizon to reach about 1.7 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 -1.4 percent in 2016Q3 and shrinks slowly over the next three years to reach -1 percent at the end of 2019.

According to PRISM, negative shocks to TFP growth and monetary policy have been significant factors dampening real output growth over the last year. Positive and offsetting contributions have largely come from the rebound in hours worked. Strong output growth in 2016Q3 is due to positive contributions from hours worked, government spending, and investment that are only partly offset by a negative contribution from TFP. TFP shocks exert a modest drag on output growth through 2018 as do monetary policy and financial shocks. By early 2018 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 surges in 2016Q3, but then largely 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 2016Q3 nowcast for core PCE inflation is 1.8 percent. The model predicts that inflation will rise to about 2 percent in 2016Q4 and then edge up to 2.2 percent by the end of 2019. With inflation projected to run at about 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 an unconstrained federal funds rate path going forward. In 2016Q4 the funds rate averages 1.1 percent and rises to 2.8 percent by the end of 2017 – a slightly slower pace of normalization than in the June forecast. By the end of 2019, PRISM has the federal funds rate at 4 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.