

**BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM**  
**DIVISION OF MONETARY AFFAIRS**  
**FOMC SECRETARIAT**

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**Date:** December 4, 2017  
**To:** Federal Open Market Committee  
**From:** James A. Clouse  
**Subject:** DSGE Models Update

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

# **System DSGE Project Forecasts**

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Keith Sill<sup>1</sup>

Federal Reserve Bank of Philadelphia

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This memo describes the economic forecasts of the four models that are currently part of the System project on dynamic stochastic general equilibrium (DSGE) models. These are the EDO (Board), PRISM (FRB Philadelphia), NY Fed, and Chicago Fed 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. For this forecast round, and going forward, we are now including forecasts from the new Chicago Fed DSGE model. Details on the Chicago model are provided in the Research Directors' Draft document that is distributed under separate cover. The DSGE model forecasts were obtained using actual data through 2017Q3 and conditioning assumptions or "nowcasts" for 2017Q4 where the sources of the nowcasts are principally the respective staff forecasts. For the NY Fed, PRISM, and EDO models the federal funds rate path is determined by the respective estimated policy reaction functions. The Chicago Fed model uses the Federal Funds rate from the Survey of Market Participants to pin down the funds rate for the next ten quarters. After that, the funds rate is determined by the model's estimated rule. For the sake of comparison, the tables include the December Tealbook forecast, as well as the 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 has growth equal to 2.3, 2.4, and 2.4 percent in 2018, 2019, and 2020, respectively. The EDO forecast is slightly weaker than September, NY Fed is slightly stronger, and PRISM is about unchanged. PRISM is the strongest forecast with annual growth averaging about 3.3 percent over the forecast horizon, while the Chicago Fed forecast is weakest with annual growth averaging about 1.5 percent. The EDO and the NY Fed growth forecasts are intermediate at, respectively, 2.6 percent and 2.1 percent over the next three years. Among the forecasts that reported last time (EDO, NY Fed, and PRISM),

disagreement across output growth forecasts, defined as the difference between the highest and lowest forecast, has fallen slightly relative to September. The Tealbook forecast is somewhat stronger than the Chicago Fed forecast but weaker than the other three forecasts. The Tealbook has output growth at 2.4 percent in 2018 falling to 1.7 percent in 2020.

Turning to inflation, the projections are similar to those made in September. The NY Fed model continues to predict that inflation will remain below the Committee's longer-run objective throughout the forecast horizon, edging up from 1.5 percent in 2018 and 2019 to 1.6 percent in 2020. The Chicago model also has inflation below target at a steady 1.7 percent over the forecast horizon. PRISM and EDO see a faster rebound with a gradual increase in inflation from 1.7 percent in 2018 to about 2 percent 2020 (PRISM is at 2 percent in 2020 and EDO is at 2.1 percent). The Tealbook inflation path is similar to EDO and PRISM, and hence somewhat stronger than the NY Fed and Chicago models.

The forecasts of the real natural rate of interest show little change for the NY Fed model and a somewhat weaker path for EDO and PRISM. EDO, NY Fed and PRISM all project an increase in the natural rate over the forecast horizon, though the magnitude of the increase varies. For the NY Fed, the natural rate increase from a current 0.3 percent to 1.3 percent at the end of 2020. For EDO, the natural rate rises from 1 percent currently to 1.6 percent at the end of 2020. For PRISM the natural rate rises from -0.4 percent to 1.7 percent in 2020. The Chicago Fed model has a downward tilt to its natural rate projection from a current estimate of 3.5 percent to 0.5 percent in 2020. Note though that the range of uncertainty in the natural rate projections is large enough that all of the forecasts lie within each other's 68 percent confidence bands at the end of 2020.

As for the output gap, EDO, NY Fed, and PRISM estimate it to be negative at present (EDO at -1 percent, NY Fed at -1.1 percent, and PRISM at -1.7 percent) and to remain so throughout the forecast horizon. The Tealbook and Chicago Fed both estimate a positive current output gap. For the Chicago Fed, the output gap declines over time from 1.5 percent currently to -0.5 percent at the end of 2020 as output growth slows. For the Tealbook the output gap rises from a current 1.3 percent to 2.1 percent in 2020. Relative to September, the paths for the output gaps in EDO, the NY Fed, and PRISM are a bit weaker.

EDO, the NY Fed, and PRISM 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. Such restraint 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, and is projected to abate further over the forecast horizon. Negative productivity shocks have also contributed to depressing economic activity over the course of the recovery, except in its very early phase. In the Chicago Fed model, monetary policy accommodation and relatively loose financial conditions keep the output gap positive through 2019. As these positive effects dissipate the drag from weak TFP growth since the financial crisis continues to exert its influence, output growth slows, and the output gap turns slightly negative in 2020.

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 (recall though that the Chicago Fed model pins down the federal funds rate over the next 10 quarters using financial market expectations. Thereafter, the estimated policy rule kicks in). In the near term, EDO predicts a more rapid rise in the funds rate to 2.4 percent at the end of 2018, compared to 2.2 percent for PRISM and NY Fed, and 2 percent for Chicago. Over the medium term the path for the funds rate is somewhat weaker than in September with the median funds rate rising from 1.2 percent in 2017Q4 to 3.3 percent in 2020Q4. The NY Fed has a more gradual pace of tightening – in line with more conservative outlooks for the path of inflation - with the federal funds rate rising but remaining below 3 percent at the end of 2020. The Chicago Fed model is similar in projecting the funds rate a 2.6 percent at the end of 2020. In contrast, EDO and PRISM predict the funds rate will rise to 3.6 percent at the end of 2020. The December Tealbook forecasts the federal funds rates to be at 2.5 percent at the end of 2018, rising to 4.0 percent at the end of 2020.

## Forecasts

Model	Real GDP Growth (Q4/Q4)							
	2017		2018		2019		2020	
	Dec	Sep	Dec	Sep	Dec	Sep	Dec	Sep
EDO - Board of Governors	<b>2.5</b> (2.5,2.5)	2.6 (2.0,3.3)	<b>2.6</b> (0.7,4.5)	2.8 (0.9,4.8)	<b>2.5</b> (0.4,4.6)	2.7 (0.6,4.7)	<b>2.6</b> (0.5,4.9)	2.8 (0.6,4.9)
New York Fed	<b>2.6</b> (2.6,2.6)	2.3 (1.3,3.2)	<b>2.0</b> (-0.6,4.4)	2.0 (-0.8,4.4)	<b>2.2</b> (-0.6,4.8)	2.0 (-0.8,4.7)	<b>2.2</b> (-0.6,4.9)	2.1 (-0.8,4.8)
PRISM - Philadelphia Fed	<b>2.5</b> (2.5,2.5)	2.7 (2.0,3.3)	<b>3.2</b> (0.4,6.5)	3.4 (0.2,6.7)	<b>3.4</b> (-0.1,6.9)	3.4 (0.0,7.0)	<b>3.2</b> (-0.2,7.0)	3.1 (-0.5,6.5)
Chicago Fed	<b>2.6</b> (2.6,2.6)	-	<b>2.0</b> (-1.4,5.4)	-	<b>1.1</b> (-2.6,4.9)	-	<b>1.5</b> (-2.3,5.4)	-
Median*	<b>2.6</b>	2.6	<b>2.3</b>	2.8	<b>2.4</b>	2.7	<b>2.4</b>	2.8
December Tealbook	<b>2.4</b>		<b>2.4</b>		<b>2.0</b>		<b>1.7</b>	

Model	Core PCE Inflation (Q4/Q4)							
	2017		2018		2019		2020	
	Dec	Sep	Dec	Sep	Dec	Sep	Dec	Sep
EDO - Board of Governors	<b>1.4</b> (1.4,1.4)	1.4 (1.3,1.6)	<b>1.7</b> (1.1,2.3)	1.7 (1.0,2.5)	<b>1.9</b> (1.1,2.8)	2.0 (1.1,2.9)	<b>2.1</b> (1.1,3.1)	2.0 (1.1,3.0)
New York Fed	<b>1.5</b> (1.5,1.5)	1.4 (1.2,1.6)	<b>1.5</b> (0.7,2.2)	1.3 (0.5,2.2)	<b>1.5</b> (0.4,2.5)	1.5 (0.4,2.6)	<b>1.6</b> (0.4,2.8)	1.7 (0.4,2.9)
PRISM - Philadelphia Fed	<b>1.3</b> (1.3,1.3)	1.3 (1.1,1.6)	<b>1.7</b> (0.6,3.0)	1.7 (0.4,3.0)	<b>1.9</b> (0.4,3.4)	1.8 (0.3,3.4)	<b>2.0</b> (0.4,3.8)	1.9 (0.2,3.6)
Chicago Fed	<b>1.3</b> (1.3,1.3)	-	<b>1.7</b> (0.9,2.5)	-	<b>1.7</b> (0.9,2.6)	-	<b>1.7</b> (0.9,2.6)	-
Median*	<b>1.4</b>	1.4	<b>1.7</b>	1.7	<b>1.8</b>	1.8	<b>1.9</b>	1.9
December Tealbook	<b>1.5</b>		<b>1.8</b>		<b>2.0</b>		<b>2.0</b>	

Model	Federal Funds Rate (Q4)							
	2017		2018		2019		2020	
	Dec	Sep	Dec	Sep	Dec	Sep	Dec	Sep
EDO - Board of Governors	<b>1.3</b> (1.3,1.3)	1.5 (1.0,2.1)	<b>2.4</b> (1.2,3.6)	2.7 (1.3,4.1)	<b>3.1</b> (1.4,4.8)	3.4 (1.6,5.2)	<b>3.6</b> (1.7,5.5)	3.8 (1.8,5.7)
New York Fed	<b>1.2</b> (1.2,1.2)	1.4 (0.6,2.2)	<b>2.2</b> (0.7,3.7)	2.1 (0.7,3.8)	<b>2.6</b> (0.9,4.5)	2.6 (0.9,4.5)	<b>2.9</b> (1.1,4.9)	2.9 (1.0,4.9)
PRISM - Philadelphia Fed	<b>1.2</b> (1.2,1.2)	1.4 (0.9,1.9)	<b>2.2</b> (0.8,3.6)	2.3 (0.7,4.2)	<b>3.1</b> (0.7,5.3)	3.1 (0.9,5.8)	<b>3.6</b> (0.8,6.3)	3.5 (0.7,6.3)
Chicago Fed	<b>1.2</b> (1.2,1.2)	-	<b>2.0</b> (1.2,2.8)	-	<b>2.6</b> (1.0,4.3)	-	<b>2.6</b> (0.4,4.8)	-
Median*	<b>1.2</b>	1.4	<b>2.2</b>	2.3	<b>2.9</b>	3.1	<b>3.3</b>	3.5
December Tealbook	<b>1.2</b>		<b>2.5</b>		<b>3.5</b>		<b>4.0</b>	

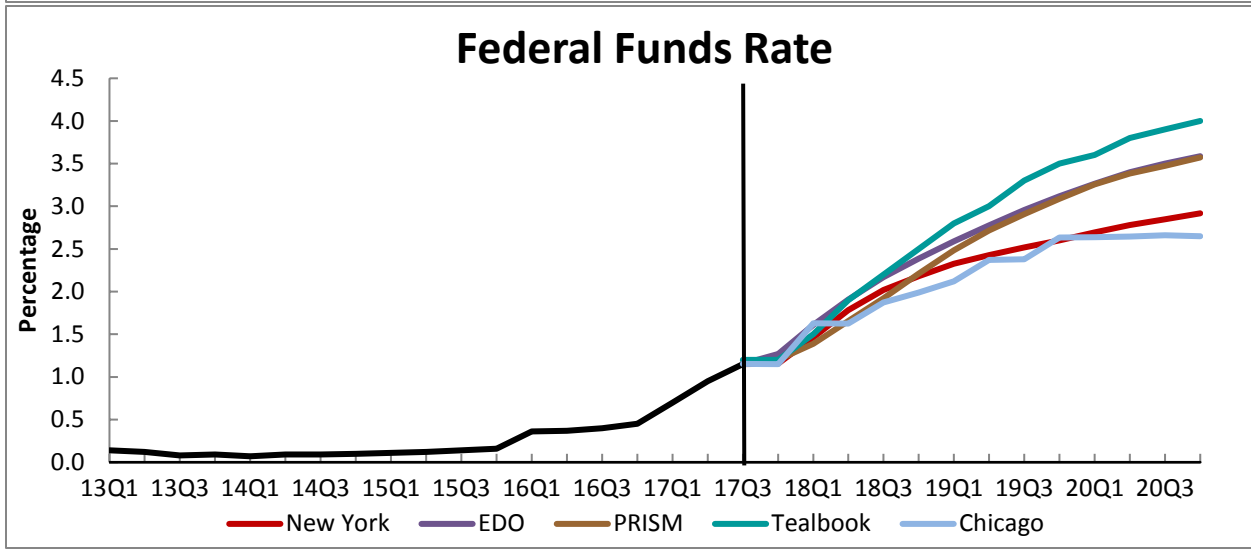
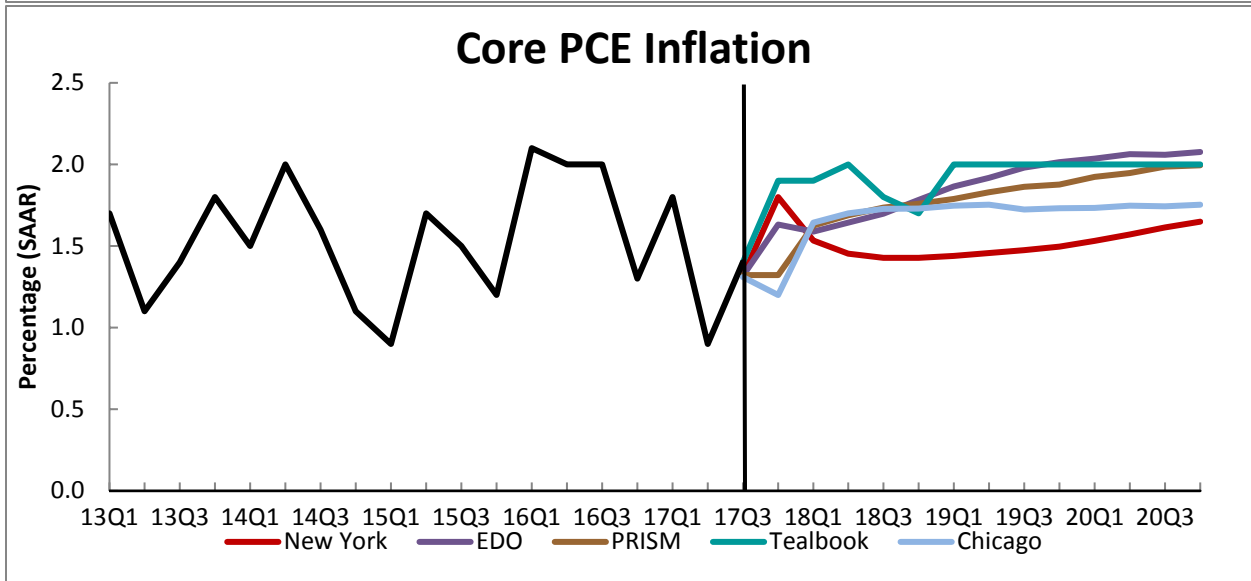
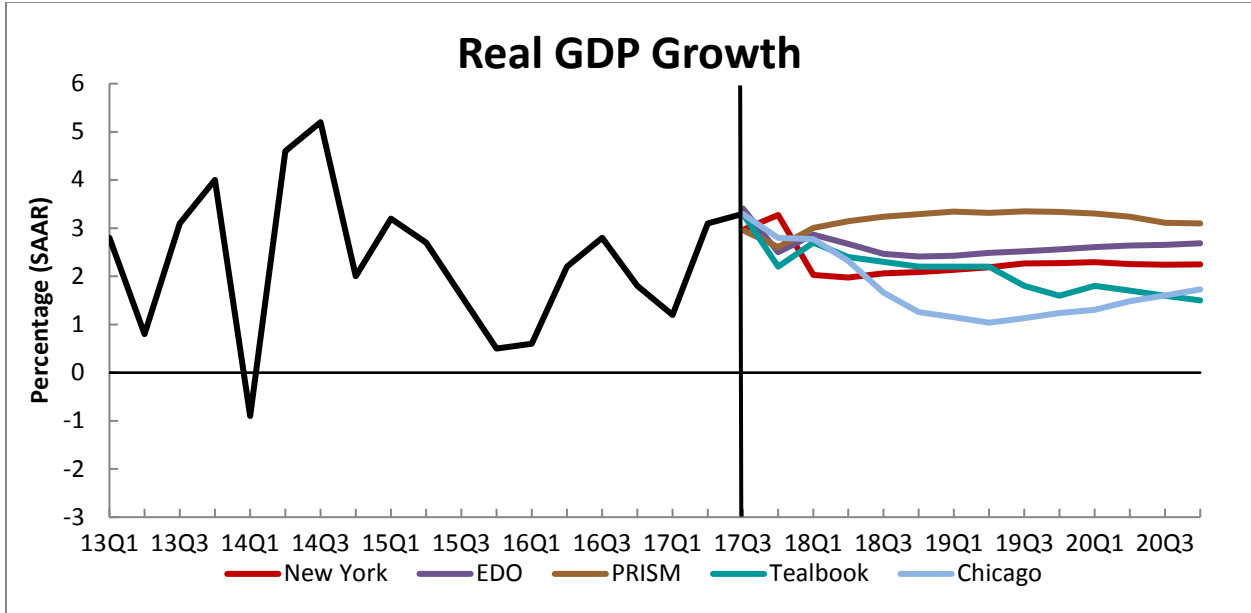
Model	Real Natural Rate of Interest r* (Q4)							
	2017		2018		2019		2020	
	Dec	Sep	Dec	Sep	Dec	Sep	Dec	Sep
EDO - Board of Governors	<b>1.0</b> (-0.7,2.7)	0.9 (-3.3,5.0)	<b>1.4</b> (-3.5,6.3)	1.4 (-3.5,6.2)	<b>1.4</b> (-3.4,6.5)	1.6 (-3.4,6.6)	<b>1.6</b> (-3.5,6.6)	1.9 (-3.2,6.7)
New York Fed	<b>0.3</b> (-1.0,1.5)	0.5 (-0.9,2.0)	<b>0.8</b> (-0.9,2.5)	0.9 (-0.9,2.6)	<b>1.1</b> (-0.8,2.9)	1.1 (-0.7,3.0)	<b>1.3</b> (-0.6,3.2)	1.2 (-0.7,3.2)
PRISM - Philadelphia Fed	<b>-0.4</b> (-2.5,1.8)	-0.6 (-3.2,2.2)	<b>0.2</b> (-2.7,3.5)	0.5 (-2.7,3.7)	<b>0.9</b> (-2.2,4.5)	1.2 (-2.8,3.9)	<b>1.7</b> (-1.9,4.6)	1.8 (-1.2,4.9)
Chicago Fed	<b>3.5</b> (3.5,3.5)	-	<b>0.7</b> (-2.1,3.5)	-	<b>0.4</b> (-2.7,3.7)	-	<b>0.5</b> (-2.7,3.7)	-
Median*	<b>0.7</b>	0.5	<b>0.8</b>	0.9	<b>1.0</b>	1.2	<b>1.5</b>	1.8
December Tealbook	-		-		-		-	

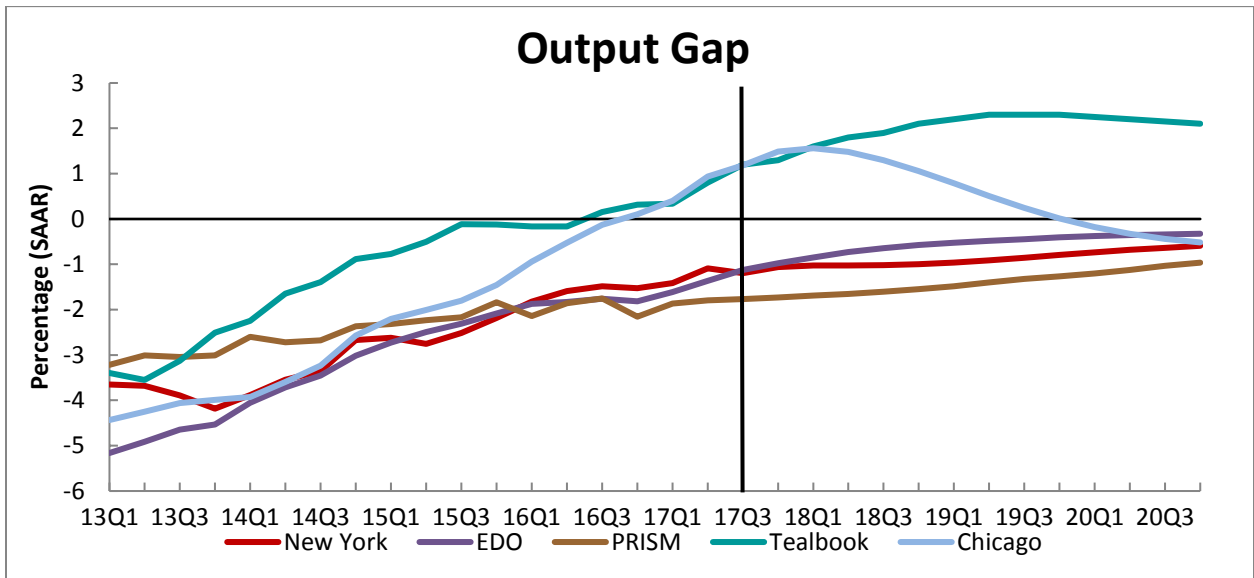
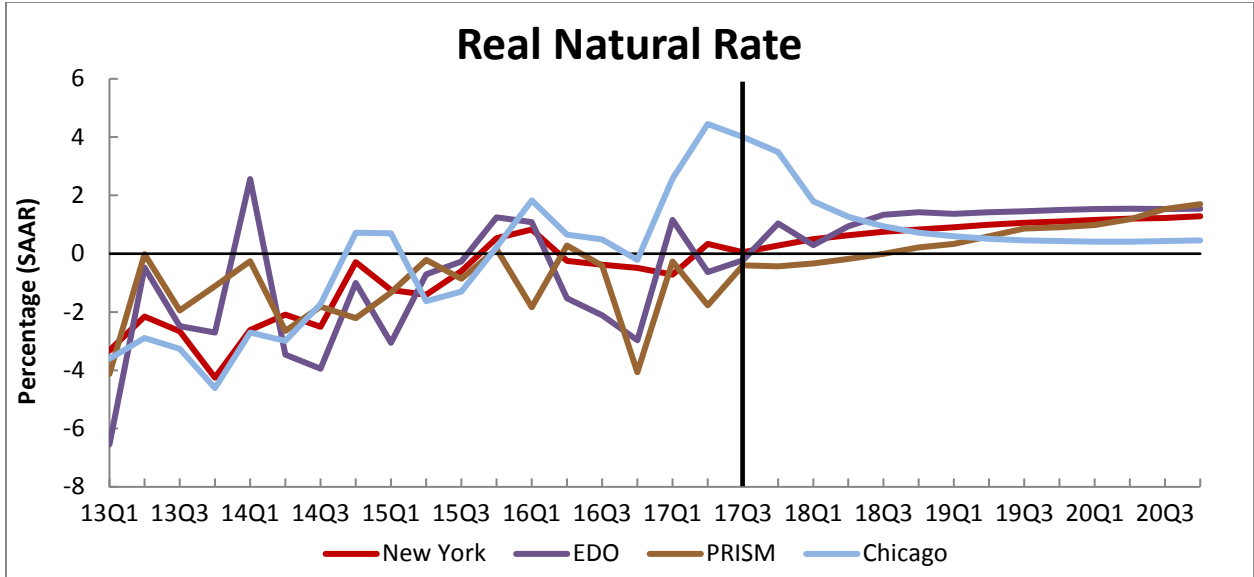
Model	Output Gap (Q4)							
	2017		2018		2019		2020	
	Dec	Sep	Dec	Sep	Dec	Sep	Dec	Sep
<b>EDO - Board of Governors</b>	<b>-1.0</b> (-1.5,-0.5)	-0.9 (-1.6,-0.3)	<b>-0.6</b> (-1.8,0.7)	-0.5 (-1.8,1.0)	<b>-0.4</b> (-2.2,1.4)	-0.3 (-2.2,1.6)	<b>-0.3</b> (-2.3,1.7)	-0.2 (-2.3,1.9)
<b>New York Fed</b>	<b>-1.1</b> (-2.3,0.2)	-0.9 (-2.2,0.5)	<b>-1.0</b> (-3.1,1.0)	-0.8 (-3.2,1.4)	<b>-0.8</b> (-3.8,1.9)	-0.6 (-3.9,2.1)	<b>-0.6</b> (-4.2,2.5)	-0.6 (-4.3,2.6)
<b>PRISM - Philadelphia Fed</b>	<b>-1.7</b> (-2.4,-0.5)	-1.6 (-2.5,-0.4)	<b>-1.5</b> (-2.8,-0.3)	-1.3 (-2.5,0.2)	<b>-1.3</b> (-2.4,0.5)	-1.0 (-2.6,0.3)	<b>-1.0</b> (-2.3,0.7)	-0.7 (-2.5,0.7)
<b>Chicago Fed</b>	<b>1.5</b> (1.5,1.5)	-	<b>1.1</b> (-0.5,2.6)	-	<b>0.0</b> (-2.6,2.6)	-	<b>-0.5</b> (-3.6,2.5)	-
<b>Median*</b>	<b>-1.1</b>	-0.9	<b>-0.8</b>	-0.8	<b>-0.6</b>	-0.6	<b>-0.6</b>	-0.6
<b>December Tealbook</b>	<b>1.3</b>		<b>2.1</b>		<b>2.3</b>		<b>2.1</b>	

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 is conditional on data through the third quarter of 2017 and on a preliminary Tealbook forecast for the fourth quarter of 2017.

Real GDP growth is 2½ percent, on average, over the projection horizon, somewhat below its long-run value of 3 percent. Inflation reaches the Committee's 2 percent objective in the fourth quarter of 2019 and then slightly overshoots the target thereafter. Below-trend real GDP growth is driven by the slow fading of risk premium shocks and accommodative monetary policy. For inflation, the EDO model interprets the weakness in inflation over the past few years as driven by negative wage markup shocks and expects them to dissipate only gradually over the projection horizon.

The output gap is estimated to be currently negative 1 percent. The output gap closes very slowly and remains at negative 0.3 percent by the end of 2020. The real natural rate of interest is projected to increase from 1 percent in the fourth quarter of 2017 to 1.5 percent at the end of 2020, 0.6 percentage point below its steady-state value of 2.1 percent. According to the EDO model, capital-specific risk premium shocks—inferred from a combination of weaker-than-expected investment and output data with stronger-than-expected consumption data over the past several years—have been holding down the output gap and the real natural rate. As these shocks slowly dissipate, the output gap closes and the real natural rate rises.

Consistent with the gradual return of inflation and the output gap to their long-run values, the federal funds rate is projected to increase gradually over the forecast horizon, reaching 3½ percent by the end of 2020. At the end of the projection horizon, the federal funds rate is still below its long-run value of 4.1 percent, reflecting the inertia in the policy rule and the persistently negative output gap even at the end of the projection horizon.

The EDO model's projection of real GDP growth in this round is slower for the next three years than it was in September 2017. The downward revision in the real GDP growth projection is mostly driven by risk premium shocks. Core PCE inflation is, on average, 4 basis points lower over the forecast horizon in this round than in September, also resulting from more negative wage markup shocks. The output gap has revised down, on average, 13 basis points since September. The projection of the real natural rate of interest has been revised down

18 basis points, on average, since September. And, consistent with the lower inflation path, the path of the federal funds rate is lower this round than in September.

### **The New York Fed Model**

The New York Fed model forecasts are obtained using data released through 2017Q3, augmented for 2017Q4 with the New York Fed staff forecasts (as of November 22) 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 2017Q4 averages up to November 22.

Based on this information, the model projects real GDP growth of 2.6 percent in 2017 on a Q4/Q4 basis, significantly stronger than the forecasts of 2.3 and 2 percent reported in September and June respectively. This projection reflects the current New York Fed staff judgmental forecast, which is somewhat more optimistic than the model's unconditional assessment of a 2.3 percent growth rate for this year. In 2018, GDP growth is anticipated to decline to 2 percent, the same as in September. Further into the future, however, the model forecasts a very gradual strengthening of activity, with GDP growth expected to reach 2.2 percent in 2019 and 2020, a slight improvement with respect to September. Consistent with this somewhat more solid growth prospects, inflation is also forecast to be higher in the medium term than expected in September, at 1.5 percent in both 2017 and 2018. However, its progress towards the FOMC's longer-run goal of 2 percent remains glacial according to the model, with core PCE inflation only reaching 1.65 percent at the end of 2020.

Notwithstanding this modest improvement in the outlook, the output gap is currently estimated to be somewhat larger in 2017Q4 than projected in September: -1.1 percent compared to -0.9 percent. This is partly because the improvement in the outlook is due to positive, but temporary, TFP shocks, as discussed below. The gap is expected to close very gradually over the course of the next several years, shrinking to -0.6 percent at the end of 2020. The natural rate of interest is estimated to be a bit lower at the end of 2017 than in September, but it is expected to continue recovering gradually over the next three years, as previously anticipated, reaching 1.3 percent at the end of 2020. The federal funds rate is projected to increase alongside its natural counterpart, reaching 2.9 percent by the end of 2020. This path translates into approximately four rate hikes in 2018, two more in 2019 and only one more in 2020.

The projections for all the variables are surrounded by notable uncertainty. For instance, the 68 percent posterior probability interval for GDP growth includes negative readings for all three years between 2018 and 2020. In comparison, the posterior probability intervals for inflation are tighter, with their upper bound never exceeding 3 percent throughout the forecast horizon.

The model attributes the above average real GDP growth rate in 2017 to continued improvement in financial conditions, as captured by positive contributions of both the financial and marginal efficiency of investment shocks. These positive forces were partly offset by low TFP growth in the first half of the year, but this drag from productivity appears to have abated in the last two quarters, contributing to the recent pickup in economic growth. As for inflation, the model attributes its recent weakness to a confluence of several factors, which continue to hold it below target over the forecast horizon. These factors include the lingering effects of the financial headwinds that have hampered the recovery, whose impact on inflation is estimated to be very persistent, as well as negative shocks to wage and price markups.

### **The PRISM Model**

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2017Q3 that are then supplemented with a 2017Q4 nowcast based on our staff's view.

PRISM forecasts that output growth will accelerate from a 2.5 percent pace in 2017 to 3.4 percent in 2019 and then ease to 3.2 percent in 2020. The nowcast pins down real output growth in 2017Q4 at 2.6 percent and core inflation at 1.3 percent. Core inflation rises gradually over the forecast horizon to reach 2 percent in 2020Q4. The PRISM projection has the funds rate following an estimated policy rule through the forecast horizon: the federal funds rate averages 1.2 percent in 2017Q4 and then advances steadily to reach 3.6 percent in 2020Q4. On balance, the PRISM forecast is very similar to the September projections.

We also forecast 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 -0.4 percent in 2017Q4. This represents a slight weakening compared to September and indeed the projected path for the natural rate over the forecast horizon 20 to 30 basis points lower. 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 2020. 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 -1.7 percent in 2017Q4 and shrinks slowly over the next three years to reach -1 percent at the end of 2020. Compared to September, PRISM sees a bit more slack in the economy over the next three years.

According to PRISM, shocks to government spending and investment made strong contributions to output growth in the second half of 2017. Partly offsetting those positive contributions were negative financial and monetary policy shocks. Going forward, financial and monetary policy shocks continue to exert a drag on output growth while government spending, investment, and labor supply make positive contributions to growth. Output growth is projected to run at a slightly-above-trend pace through the forecast horizon. Consumption growth (nondurables plus services) ran at a below trend pace in the second half of 2017 held down by shocks to TFP, government spending and monetary policy. Going forward, consumption growth accelerates toward its trend pace as those shocks wane and as the labor and financial markets rebound. Consumption growth is back to trend in 2020. Shocks to the marginal efficiency of investment led to strong investment growth in the second half of 2017. As these shocks wane, investment growth settles to around a 4.5 percent pace over the next few quarters and then gradually eases to about 2.5 percent in 2020. 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 2017Q4 nowcast for core PCE inflation is 1.3 percent. The model predicts that inflation rises gradually to 2 percent by the end of 2020. With inflation edging up to target over the forecast horizon, 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. In 2017Q4 the funds rate averages 1.2 percent, rising to 2.2 percent in 2018Q4 and 3.1 percent in 2019Q4 -- a similar pace of normalization compared to the September 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.

### **The Chicago Fed Model**

The Chicago Fed's DSGE model forecast is constructed using data through 2017Q3 supplemented by judgmental assumptions for 2017Q4 GDP, consumption and investment growth, core PCE inflation, and expected core PCE inflation one-quarter ahead and over the next 10 years. The federal funds rate path for 10 quarters out is pinned down by data on expected future funds rates from survey data which are rationalized in the model by forward guidance shocks. At the conclusion of the 10 quarters the estimated policy rule takes over. The federal funds rate path rises gradually and settles down at about 2.6 percent in 2020.

Since 2017Q4 GDP growth is taken as given at 2.8 percent and with the rest of the year already in hand, we have 2017 (Q4/Q4) growth coming in at 2.6 percent, which is above the model's post-2008Q4 steady state of 2 percent. The model projects GDP growth declines to its potential in 2018 and then to 1.1 percent in 2019 before rebounding somewhat to 1.5 percent in 2020 along a fairly rapid trajectory back to steady state. Core PCE inflation is projected to rebound from the low rates of this year, to 1.7 percent next year. However it is essentially flat from then on so the model does not project a return to 2 percent (the model's steady state) over the forecast horizon. Based on the 68 percent coverage intervals, the model sees little chance of deflation over the forecast horizon, but the relatively slow GDP growth and corresponding wide coverage interval suggest a recession is not unlikely.

The strong growth of recent quarters is interpreted by the model primarily as reflecting positive shocks to permanent neutral technology, relatively loose financial conditions arising from a reduction in demand for government bonds, and a high degree of monetary accommodation from forward guidance. Over the forecast horizon the good news on technology lifts growth in the near term but the tightening of financial conditions and the gradual removal of accommodation act as a drag on growth in the outer years of the forecast.

In the several years prior to 2017 the below 2 percent realizations of inflation are explained primarily by measurement error and price markup shocks. The model uses these shocks as a last resort when other more easily interpretable shocks cannot explain inflation. These shocks are more important after the financial crisis than before it. The model explains much of the low inflation readings over the last year with transitory measurement error along

with a strong undercurrent of downward pressure from past technology shocks. Going forward this strong undercurrent comes to dominate the forecast. Accordingly, inflation does not return to 2 percent over the forecast horizon because of these shocks.

This may seem puzzling at first sight. Our model has the same prediction as most New Keynesian models in that starting from steady state inflation drops after a positive neutral technology shock. It rises gradually toward steady state over a two year horizon. However after two years it rises above steady state and stays there for a very long time, about ten years. This pattern of the impulse response function means that the recent positive technology shocks drive inflation down in the near term. But this is not the reason why the forecast stays so low for so long. Inflation stays low because of the numerous relatively large negative technology shocks the model infers in the years following the financial crisis. Because of the very persistent effects of these shocks they will act as a drag on inflation for years to come.<sup>2</sup>

We also forecast the natural rate of interest and the output gap. The natural rate is the contemporaneous spot rate on 3-month government bonds that would prevail if wages and prices were fully flexible. We measure the output gap as the log deviation of output from its flexible wage and price counterfactual. The natural rate in this class of models is notoriously volatile so that positive output gaps can translate into relatively large positive deviations of the natural rate from its steady state (in our case 1 percent). The model sees a positive output gap over the last year peaking at 1.5 percent at the end of 2017. These positive gaps come with a relative high natural rate at the end of 2017, 3.5 percent. However as growth is projected to slow over the coming years the output gap falls gradually so that it is minus 0.5 percent by the end of 2020. This trajectory is associated with declines in the natural rate, which falls to 0.7 percent by the end of 2018 and flattens out near 0.4% in 2019 and 2020. The driving forces of these dynamics are similar to those driving GDP growth and inflation. Monetary policy accommodation and relatively loose financial conditions keep the output gap positive and the natural rate high. As these positive effects dissipate the drag from poor technology growth since the financial crisis takes hold.

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<sup>2</sup> Our measurement equation for expected inflation over the next 10 years has a measurement error term. The model reconciles this inflation forecast with the close to 2 percent survey measures for PCE inflation over the next years using this measurement error.