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From: Matthew M. Luecke
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 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), New York 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. The DSGE model forecasts were obtained using actual data through 2018Q3 and nowcasts for 2018Q4. The New York Fed, PRISM, and EDO models use their estimated policy rules to determine the federal funds rate path. In contrast, 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. Thereafter, that model's estimated interest rate rule governs its policy forecasts. For the sake of comparison, the tables include the December Tealbook forecasts, 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. Finally, 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 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 equal to 3.1 percent in 2018, 2.2 percent in 2019, and 2.1 percent in both 2020 and 2021. PRISM continues to have the strongest overall forecast, with growth averaging about 3.2 percent over the medium term. The New York Fed model has the weakest forecast over the next three years, predicting an average annual growth rate of about 1.9 percent. The EDO and the Chicago Fed growth forecasts are closer to the New York Fed forecast in magnitude, at, respectively, 2.2 percent and 2.0 percent over the medium term. The New York Fed forecast is a bit stronger at all horizons from September, while PRISM and EDO forecasts are slightly weaker. The Chicago Fed forecast is stronger throughout 2020, but revised downwards in 2021. Disagreement across output growth forecasts, defined as the difference between the highest and lowest forecast, has fallen somewhat relative to September, mainly due to the higher forecast

path from the New York Fed model. The Tealbook forecasts for 2019 and 2020, at 2.4 percent and 2 percent, respectively, are somewhat weaker than PRISM forecasts but broadly similar to the other three forecasts. The Tealbook has output growth stepping down to 1.4 percent in 2021 from 2 percent in 2020, weaker than the four models' projections in the long run.

Turning to inflation, all of the forecasts have core PCE inflation near 2 percent in 2018. While the median of different model forecasts continues to indicate that inflation will be at the Committee's target over the next three years, as it did in September, the New York Fed model's medium term forecast differs somewhat from the others. In particular, the New York Fed model predicts that inflation will remain below the Committee's longer-run objective throughout the forecast horizon, falling from 1.8 percent in 2018 to 1.5 percent in 2021. EDO, PRISM and the Chicago Fed, on the other hand, continue to predict inflation will be hovering around the Committee's 2 percent target over the next three years. The Tealbook forecast for inflation increase from 1.8 percent in 2018 to 2 percent in 2019 and stays there for the rest of the forecast horizon.

Looking at the medians across the four models' point forecasts, the real natural rate, at 1.4 percent, is projected to be significantly higher in 2018 compared to September, primarily driven by an upward revision in EDO forecast, but very little changed over the following three years. The real natural rate is estimated to moderate to 1.1 percent in 2019 before rising gradually to 1.5 percent in 2021. Note, however, that individual model projections for the natural rate are surrounded by large enough uncertainty that all of the forecasts lie within each other's 68 percent confidence bands at the end of 2021.

Estimates of the output gap show considerable dispersion across the models and range from a low of -2.5 percent in PRISM to a high of 0.6 percent in the Chicago Fed model. EDO and the New York Fed see small negative output gaps at the end of 2018Q4; and both models estimate the output gap to be fairly stable over the forecast horizon, ranging from -0.2 in 2018Q4 to -0.4 in 2021Q4 for the New York Fed, and from -0.2 percent to -0.3 percent for EDO. PRISM continues to predict a negative but diminishing output gap all the way till 2021. In contrast, the Chicago Fed model estimates a positive output gap for 2018Q4 (0.6 percent) but expects output to fall by 2021, with the positive gap dissipating.

Notwithstanding the dispersion across the models' projections on the future path of output growth, the slow fading of accommodative financial conditions, negative productivity shocks and the gradual removal of monetary accommodations have generally been estimated to contribute to slower growth over the medium term.

Finally, while all the models predict a rising path for the federal funds rate, the expected speed of normalization significantly varies across the models, consistent with their differing projections on the future path of output growth and inflation. PRISM and EDO forecasts display a relatively steeper path for the federal funds rate, starting at 2.2 percent in the last quarter of 2018 and gradually reaching 3.9 and 4.0 percent, respectively, in 2021Q4. The New York Fed and the Chicago Fed project a shallower path with the federal funds rate at 2.2 percent and 2.4 percent in 2018Q4, respectively, and increasing to 2.8 and 3.2 percent at the end of 2021. The December Tealbook forecasts the federal funds rates to be 2.2 percent at the end of 2018. Its pace of normalization thereafter is faster than predicted by all the four models, with the federal funds rate reaching 4.7 percent in 2021.

Forecasts

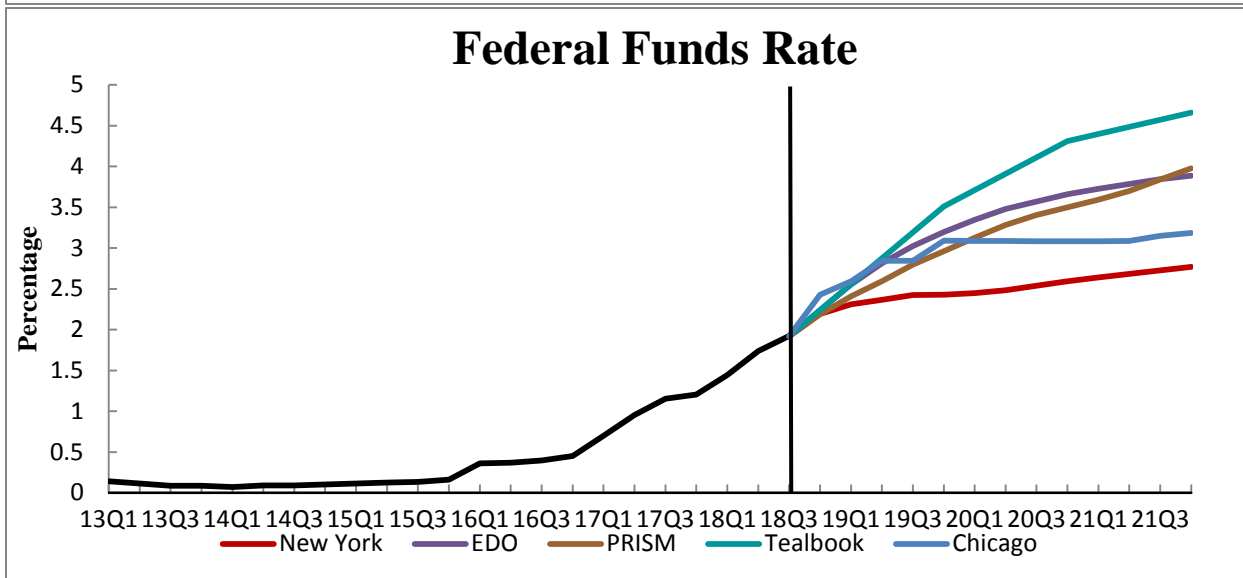
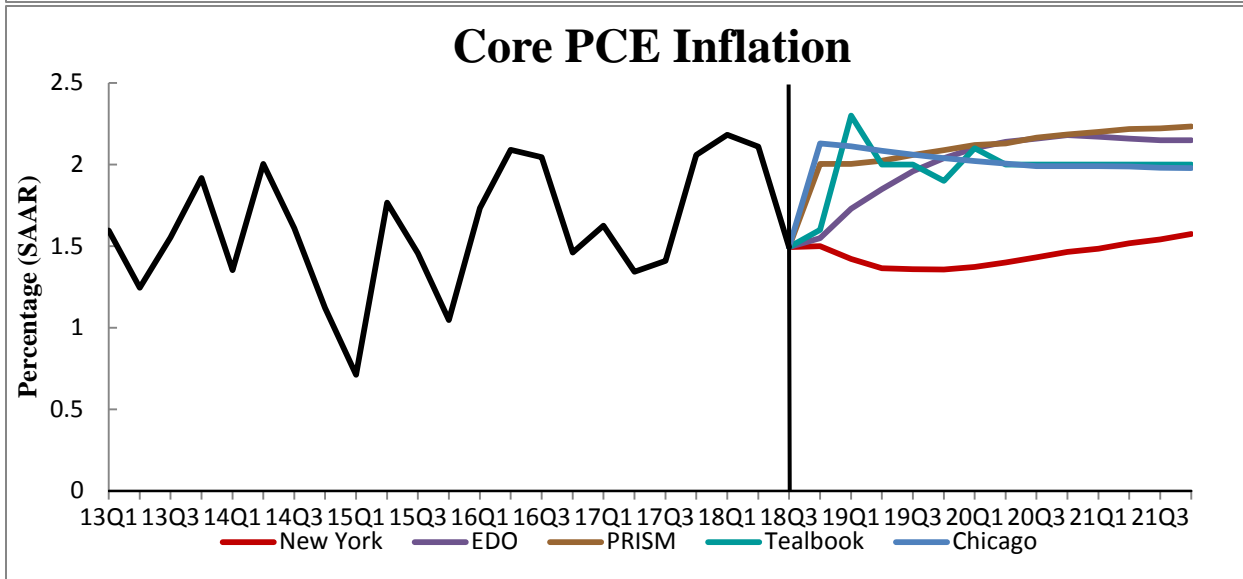
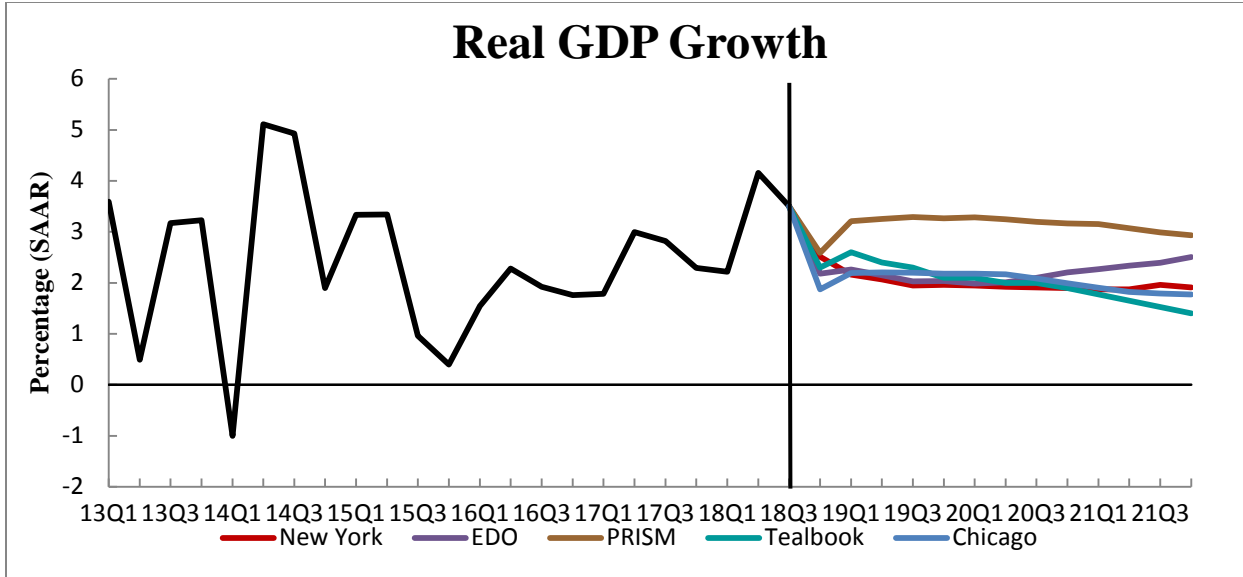
Model	Output Growth (Q4/Q4)							
	2018		2019		2020		2021	
	December	September	December	September	December	September	December	September
EDO - Board of Governors	3.0 (3.0,3.0)	3.2 (2.5,3.8)	2.1 (0.3,4.0)	2.3 (0.3,4.2)	2.1 (0.1,4.1)	2.2 (0.2,4.3)	2.4 (0.2,4.6)	2.5 (0.3,4.7)
New York Fed	3.1 (3.1,3.1)	3.0 (2.1,3.9)	2.0 (-0.6,4.3)	1.7 (-1.1,4.2)	1.9 (-1.0,4.5)	1.6 (-1.2,4.2)	1.9 (-1.0,4.6)	1.7 (-1.1,4.4)
PRISM - Philadelphia Fed	3.1 (3.1,3.1)	3.2 (2.6,3.9)	3.3 (0.5,6.4)	3.4 (0.3,6.7)	3.3 (0.0,6.7)	3.4 (0.1,6.9)	3.1 (-0.2,6.7)	3.1 (-0.3,6.6)
Chicago Fed	3.3 (3.3,3.3)	2.8 (1.9,3.8)	2.2 (-2.1,6.5)	1.8 (-2.7,6.2)	2.1 (-2.6,6.8)	2.0 (-2.6,6.7)	1.8 (-3.0,6.6)	2.1 (-2.7,6.9)
Median Forecast*	3.1	3.1	2.2	2.1	2.1	2.1	2.1	2.3
December Tealbook	3.0		2.4		2.0		1.4	

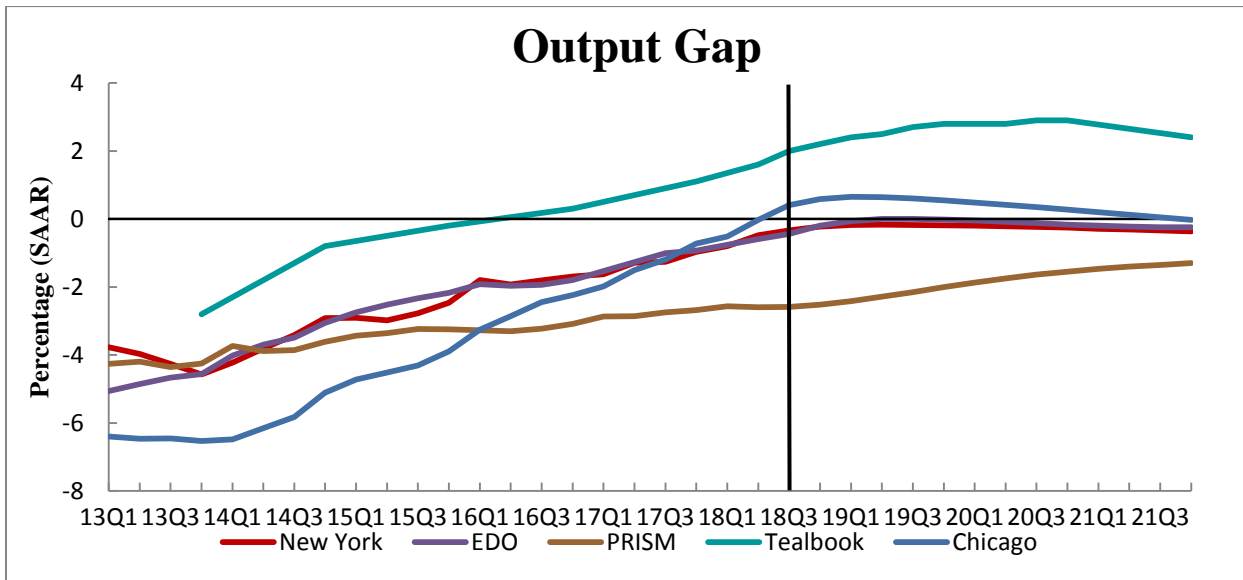
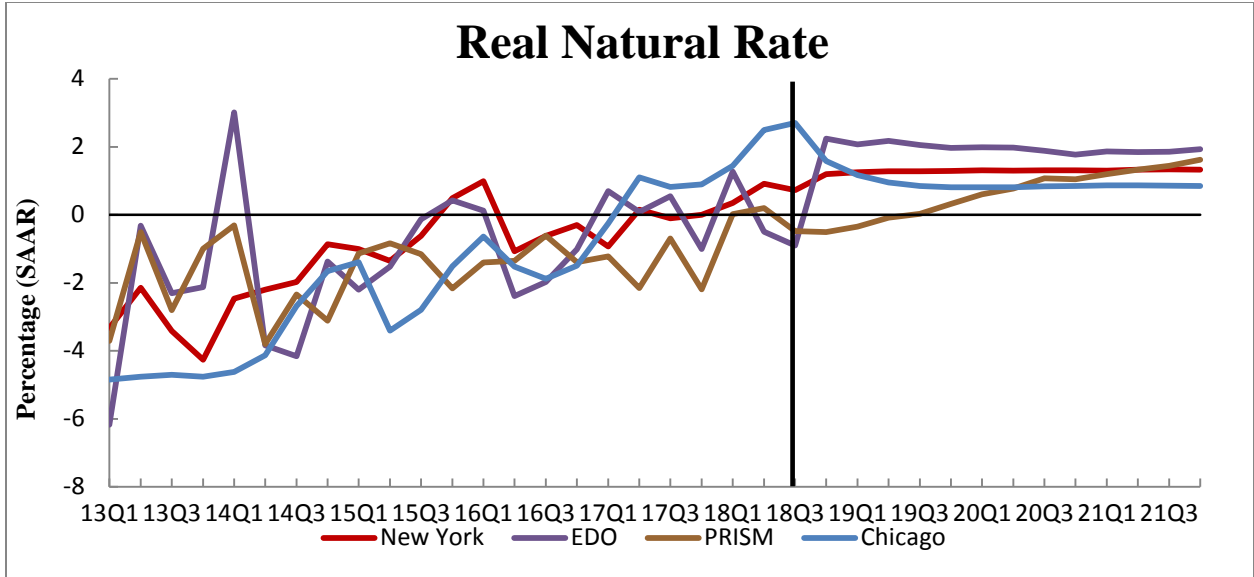
Model	Core PCE Inflation (Q4/Q4)							
	2018		2019		2020		2021	
	December	September	December	September	December	September	December	September
EDO - Board of Governors	1.9 (1.9,1.9)	2 (1.8,2.1)	1.9 (1.3,2.5)	1.9 (1.2,2.7)	2.2 (1.3,3.0)	2.1 (1.2,3.0)	2.2 (1.3,3.0)	2.1 (1.2,3.0)
New York Fed	1.8 (1.8,1.8)	1.9 (1.7,2.2)	1.4 (0.6,2.1)	1.6 (0.7,2.4)	1.4 (0.4,2.4)	1.5 (0.5,2.6)	1.5 (0.3,2.7)	1.6 (0.4,2.8)
PRISM - Philadelphia Fed	2.0 (2.0,2.0)	2.0 (1.8,2.3)	2.1 (0.9,3.2)	2 (0.8,3.4)	2.2 (0.7,3.7)	2.2 (0.6,3.7)	2.2 (0.7,3.8)	2.3 (0.6,3.9)
Chicago Fed	2.0 (2.0,2.0)	2.0 (1.8,2.2)	2.1 (1.3,2.9)	2.0 (1.1,2.8)	2.0 (1.1,2.9)	2.0 (1.1,2.8)	2.0 (1.1,2.9)	2.0 (1.1,2.9)
Median Forecast*	1.9	2.0	2.0	2.0	2.1	2.1	2.1	2.1
December Tealbook	1.8		2.0		2.0		2.0	

Model	Federal Funds Rate (Q4)							
	2018		2019		2020		2021	
	December	September	December	September	December	September	December	September
EDO - Board of Governors	2.2 (2.2,2.2)	2.3 (1.8,2.8)	3.2 (2.0,4.4)	3.2 (1.8,4.6)	3.7 (1.9,5.4)	3.6 (1.8,5.5)	3.9 (2.0,5.8)	3.9 (1.9,5.8)
New York Fed	2.2 (2.2,2.2)	2.1 (1.0,3.3)	2.4 (0.9,4.1)	2.5 (0.9,4.3)	2.6 (0.9,4.4)	2.7 (0.9,4.5)	2.8 (0.9,4.8)	2.8 (1.0,4.8)
PRISM - Philadelphia Fed	2.2 (2.2,2.2)	2.3 (1.7,2.7)	3.0 (1.6,4.5)	3 (1.4,4.6)	3.5 (1.1,5.7)	3.5 (1.3,5.9)	4.0 (1.2,6.4)	3.9 (1.1,6.5)
Chicago Fed	2.4 (2.4,2.4)	2.3 (2.2,2.4)	3.1 (2.3,3.9)	3.0 (1.9,4.0)	3.1 (1.4,4.8)	3.2 (1.3,5.1)	3.2 (0.9,5.5)	3.0 (0.7,5.3)
Median Forecast*	2.2	2.3	3.0	3.0	3.3	3.4	3.5	3.5
December Tealbook	2.2		3.5		4.3		4.7	

Model	Real Natural Rate of Interest r* (Q4)							
	2018		2019		2020		2021	
	December	September	December	September	December	September	December	September
EDO - Board of Governors	2.2 (0.5,4.0)	0.8 (-3.3,4.9)	1.9 (-2.9,6.9)	1.7 (3.2,6.7)	1.8 (-3.3,6.8)	1.7 (-3.4,6.9)	1.9 (-3.1,7.0)	1.7 (-3.4,6.7)
New York Fed	1.2 (-0.1,2.5)	1.1 (-0.5,2.6)	1.3 (-0.4,3.0)	1.3 (-0.4,3.1)	1.3 (-0.5,3.2)	1.3 (-0.5,3.1)	1.3 (-0.6,3.2)	1.3 (-0.6,3.2)
PRISM - Philadelphia Fed	-0.5 (-3.3,2.0)	-0.4 (-3.2,2.0)	0.3 (-2.7,3.4)	0.4 (-3.0,3.6)	1.1 (-2.2,4.0)	1 (-2.0,4.2)	1.6 (-1.7,4.7)	1.5 (-1.5,5.0)
Chicago Fed	1.6 (1.6,1.6)	1.3 (-0.5,3.0)	0.8 (-2.0,3.7)	0.7 (-2.3,3.7)	0.8 (-2.4,4.1)	0.8 (-2.6,4.1)	0.9 (-2.6,4.2)	0.8 (-2.6,4.2)
Median Forecast*	1.4	1.0	1.1	1.0	1.2	1.2	1.5	1.4

Model	Output Gap (Q4)							
	2018		2019		2020		2021	
	December	<i>September</i>	December	<i>September</i>	December	<i>September</i>	December	<i>September</i>
EDO - Board of Governors	-0.2 (-0.7,0.3)	-0.3 (0.9,0.3)	0.0 (-1.3,1.2)	-0.1 (-1.6,1.3)	-0.2 (-1.9,1.6)	-0.2 (-2.1,1.7)	-0.3 (-2.3,1.8)	-0.2 (-2.3,1.9)
New York Fed	-0.2 (-1.5,1.0)	-0.1 (-1.5,1.3)	-0.2 (-2.4,1.8)	-0.1 (-2.6,2.1)	-0.3 (-3.3,2.4)	-0.3 (-3.5,2.5)	-0.4 (-4.0,2.8)	-0.4 (-4.2,2.7)
PRISM - Philadelphia Fed	-2.5 (-3.4,-0.9)	-2.5 (-3.3,-0.9)	-2.0 (-3.4,-0.5)	-2 (-3.6,-0.8)	-1.6 (-3.2,-0.1)	-1.5 (-3.0,0.0)	-1.3 (-2.6,0.7)	-1.2 (-3.0,0.3)
Chicago Fed	0.6 (0.6,0.6)	1.2 (0.7,1.6)	0.5 (-1.0,2.1)	0.4 (-1.5,2.4)	0.3 (-2.4,2.9)	0.1 (-2.7,2.9)	0.0 (-3.1,3.1)	0.0 (-3.1,3.2)
Median Forecast*	-0.2	-0.2	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3
December Tealbook	2.2		2.8		2.9		2.4	





Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model's forecast is conditional on data through the third quarter of 2018 and on a preliminary Tealbook forecast for the fourth quarter of 2018.

Real GDP growth is 2.2 percent, on average, over the next three years, below its trend rate of 2.9 percent. Inflation reaches the Committee's 2 percent objective in the fourth quarter of 2019 and hovers around a level slightly above 2 percent thereafter. Below-trend real GDP growth is driven by the slow fading of favorable risk premium shocks and the waning effects of the currently accommodative stance of monetary policy. On the nominal side, for a number of years, wages have been below the level consistent with the model's wage Phillips curve, holding down marginal cost and depressing inflation over that period. A gradual fading of these wage shocks will continue, contributing to the upward trajectory for inflation. Persistently adverse capital-specific risk premium shocks also contribute to the projected rise in inflation by raising the marginal cost of production.

The output gap, currently estimated to be negative 0.2 percent, is projected to close in the third quarter of 2019 but falls slightly thereafter, reaching negative $\frac{1}{4}$ percent in the last quarter of 2021. The real natural rate of interest—estimated to be $2\frac{1}{4}$ percent in the fourth quarter of 2018—is projected to fall slightly to 1.9 percent in the final quarter of 2021, 0.2 percentage point below its steady-state value of 2.1 percent. The trajectories of the natural rate of interest and the output gap are heavily driven by the model's view that capital stocks are currently below those that would have prevailed in the absence of nominal rigidities and the view that the investment-related shocks responsible for this condition are likely to dissipate slowly.

With inflation near the Committee's objective, the output gap reasonably close to zero, and the current federal funds rate still low, the federal funds rate increases toward the long-run value of 4.1 percent over the forecast horizon. The pace of the increase is gradual, reflecting the inertia in the Taylor rule. The federal funds rate reaches 4 percent by the end of 2021, a bit below its long-run value.

The data on recent GDP growth and core PCE inflation have been weaker than the EDO model had projected in September, and the model interprets much of the surprise as due to slower total factor productivity (TFP) growth and a transitory reduction in wage markups.

Accordingly, the EDO model's forecast of real GDP growth in this round is modestly lower over the forecast horizon—about 13 basis points, on average—as the temporary deceleration in TFP growth gradually fades. Since September, core PCE inflation has been revised down 8 basis points, on average, in the first half of 2019. Thereafter, core PCE inflation is a touch higher than in September. The output gap is a shade higher over the forecast horizon relative to the September round. The estimated path of the real natural rate of interest has been revised up appreciably since September because the negative revisions to TFP growth raise the natural rate of interest in the short run. The path of the federal funds is essentially unchanged since September, as the effects of the small upward revision in the output gap partially offset the effects of the initial downward revisions of core PCE inflation.

The New York Fed Model

The New York Fed model forecasts are obtained using data released through 2018Q3, augmented for 2018Q4 with the New York Fed staff forecasts (as of December 4) 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 2018Q4 averages up to December 4.

The model projects real GDP growth of 3.1 percent in 2018 on a Q4/Q4 basis, which is a tad higher than the September forecast of 3 percent growth for 2018. This projection fully reflects the current New York Fed staff judgmental forecast, which is similar to the model's unconditional assessment of a 3 percent growth rate for this year. However, this is only a temporary surge, as GDP growth is anticipated to decline to 2.0 percent in 2019, and to 1.9 percent in both 2020 and 2021, a similar path compared to the September forecast. For comparison, in the September projections GDP growth was anticipated to move down to 1.7 percent, 1.6 percent and 1.7 percent in 2019, 2020 and 2021, respectively. The projections of inflation have been revised downwards slightly at all horizons compared to the model's projections in September. Inflation is forecast to be just below the FOMC's longer run goal this year at 1.8 percent, 0.1 percentage points lower than the forecast in September. The model projects that inflation will decline to 1.4 percent in 2019, 0.2 percentage points below the September forecast, and will remain around that value for the rest of the forecast horizon.

The output gap is estimated to be slightly larger in 2018 than projected in September: -0.2 percent compared with -0.1 percent. The gap is forecast to stay around this level in 2019 before opening up again to -0.3 percent in 2020 and -0.4 percent in 2021. The projection for the natural rate of interest is 1.2 percent in 2018, 0.1 percentage point higher than the September projection, and rises to 1.3 percent in 2019, remaining at that level for the rest of the forecast horizon. The federal funds rate is forecast to rise steadily, as anticipated in September, reaching 2.8 percent in 2021Q4 from its 2018Q4 level of 2.2 percent. This shallower path translates into approximately two more hikes throughout the forecast horizon.

The projections for all variables are surrounded by significant uncertainty. For instance, the 68 percent posterior probability interval for GDP growth includes negative readings for all the years between 2019 and 2021. In comparison, the posterior probability intervals for inflation are tighter, with their upper bound below 3 percent throughout the forecast horizon.

The model attributes the above average real GDP growth rate in 2018 to continued improvement in financial conditions, as reflected in positive contributions of both the financial and marginal efficiency of investment shocks. These positive forces are reinforced by improvement in productivity in the second half of the year, contributing to the surge in economic growth in 2018. Over the medium term, however, the temporary boost from productivity abates, while the contribution of accommodative financial conditions tapers down and is offset by the gradual withdrawal of monetary accommodation. The model projects near-target inflation for 2018, driven by a temporary increase in price markups. However, as in the previous quarters, the model projects inflation returning to below target in 2019 and beyond. The decline in inflation is driven primarily by negative shocks to wage and price markups, but also reflects lingering effects of the financial headwinds that hampered the recovery. The federal funds rate path is projected to remain below its long-run level of 4 percent throughout the forecast horizon owing to persistence in the interest rate rule, a weak inflation projection, and a persistently negative output gap.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2018Q3 that are then supplemented with a 2018Q4 nowcast based on the most recent Macroeconomic Advisors model forecast.

The PRISM forecast is based on a 2018Q4 nowcast for real GDP growth of 2.6 percent and a core PCE inflation nowcast of 2 percent. These projections lead to an estimate for 2018 real output growth of 3.1 percent and core PCE inflation of 2 percent. Looking ahead, real output growth rises to 3.3 percent in 2019 and then declines slightly to 3.1 percent by 2021. Output growth is at a modestly above-trend pace through the forecast horizon. Core inflation moves up to 2.1 percent in 2019 and 2.2 percent in 2020 and 2021 and so displays only a slight overshooting of the FOMC target. The PRISM projection has the federal funds rate following an estimated policy rule through the forecast horizon that reacts to inflation and an output gap. To keep the inflation rate near target, the funds rate averages 2.2 percent in 2018Q4 and rises gradually to 4 percent in 2021Q4.

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 -0.5 percent in 2018Q4. With output growth running at an above-trend pace the natural rate rises over the forecast horizon to reach about 1.6 percent at the end of 2021. Our estimate of the output gap is derived from the log deviation of real output from its flexible-price counterfactual level. The estimated output gap is at -2.5 percent in 2018Q4 and shrinks slowly over the next three years to reach -1.3 percent at the end of 2021.

According to PRISM, near-trend output growth in 2018Q4 is driven by positive shocks to investment and labor supply that are largely offset by productivity, financial, and monetary policy shocks. Investment and labor supply shocks are expected to make positive and persistent contribution to output growth over the next three years. Government spending shocks provide only a modest boost to output growth over the medium term. On balance, the positive contributions from shocks to investment, labor supply, and government are enough to keep output growth slightly above its trend pace over the forecast horizon. Consumption growth (nondurables plus services) runs at a slightly below trend pace over the projection period, held down by shocks to TFP and government. In contrast, investment growth runs at a strong pace

over the forecast horizon driven by shocks to the marginal efficiency of investment and labor supply. Negative financial shocks act as a partial brake on investment growth over the next three years and by the end of 2021, investment growth tapers down to about 2.1 percent or so. The model continues to imply that the de-trended level of output is below its steady state and an important factor in accounting for this gap is the lower-than-trend level of aggregate hours worked, which the model generates through a combination of labor supply shocks, financial shocks, and government spending shocks.

The 2018Q4 nowcast for core PCE inflation is 2 percent and the model predicts that inflation hovers around that level over the next three years. With inflation running close 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.

The forecast is implemented with a rule-based federal funds rate path. By 2019Q1 the funds rate averages 2.4 percent, rising to 3 percent in 2019Q4 and 4 percent in 2021Q4 -- a similar path 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 2018Q3 supplemented with 2018Q4 expected inflation, both one-quarter ahead and over the next 10 years, taken from the Fourth Quarter SPF survey.² We used data on expected future funds rates from the September 17 Survey of Market Participants augmented with OIS rate changes since then to determine the federal funds rate path for the next 10 quarters.³ The model rationalizes

² Our estimation and forecasting matches two inflation measures to our model's inflation core CPI and core PCE, with appropriate corrections for their different mean inflation rates. Our forecasts reported in the previous system DSGE memo used only reported expectations for core PCE. We have added the CPI expectations to avoid problems with forecasters simply repeating the FOMC's inflation target back to the SPF as their long-run forecast.

³ Specifically, we take the SMP results as our baseline path, and we adjust each rate on it by the change in the OIS rate for the analogous quarter from September 17 through November 29.

these expectations with forward guidance shocks. Beginning in 2021Q3, the model's estimated policy rule takes over.

The model's forecast for 2018 GDP growth, 3.3 percent, is essentially determined by the three quarters of data in hand. The analogous GDP forecasts for 2019, 2020, and 2021 are equal to 2.2 percent, 2.1 percent, and 1.8 percent, respectively. These are broadly similar to the forecasts we reported in the previous DSGE memo (1.8 percent, 2.0 percent, and 2.1 percent). The differences between our previous and current forecasts mostly arise from a technical adjustment to how we handle market expected interest rates.

Our forecasts for Q4/Q4 core PCE inflation are equal to 2 percent, 2.1 percent, 2 percent and 2 percent for 2018, 2019, 2020, and 2021, respectively. This is basically unchanged from the forecast we gave in the previous DSGE memo. Recently received inflation data has only reinforced the conclusion that inflation will be close to the FOMC's target in the short and medium term.

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 model forecasts end-of-year output gaps for 2018 through 2021 of 0.6 percent, 0.5 percent, 0.3 percent, and 0 percent. We forecast the natural rate of interest at the end of the year for 2018 through 2021 to equal 1.6 percent, 0.8 percent, 0.8 percent, and 0.9 percent. (The long-run natural rate equals 0.95 percent.)