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To: Federal Open Market Committee

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), Chicago Fed and New York 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 2018Q1 and nowcasts for 2018Q2. 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 June 1 Tealbook forecasts, as well as the model forecasts prepared for the March 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 adjustments 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 has growth equal to 2.6 percent in 2018, and 2.2 percent for both 2019 and 2020. While PRISM continues to have the strongest forecast with annual growth averaging about 3.0 percent over the forecast horizon, the Chicago Fed model has the weakest forecast predicting an average annual growth rate of about 1.7 percent. The EDO and the New York Fed growth forecasts lie between the PRISM and Chicago Fed forecasts, at, respectively, 2.7 percent and 2.0 percent over the next three years. All four models' projections for 2019 and 2020 were relatively unchanged since March, while those for 2018 are up sharply for EDO, PRISM, and the Chicago Fed. Disagreement across output growth forecasts, defined as the difference between the highest and lowest forecasts, has changed little since March. The Tealbook forecast is 0.2 percent higher than the median DSGE forecast for 2018 and 2019 and 0.4 percent lower than that forecast for 2020.

Proceeding to core PCE inflation, both PRISM and Chicago Fed predict that the committee will slightly overshoot its target in 2018 and achieve its target in 2019 and 2020. EDO forecasts 1.9 percent inflation for 2018, 1.8 percent for 2019, and 2.0 percent for 2020. In contrast, the New York Fed model continues to predict that inflation will remain below the Committee's longer-run objective throughout the forecast horizon, gliding from 1.9 percent in 2018, to 1.5 percent in 2019 and 2020. The median DSGE inflation forecasts, 2.0 percent, 1.9 percent, and 2.0 percent for 2018, 2019, and 2020 match their Tealbook counterparts closely.

The expected speed of normalization in the federal funds rate varies across the three models that employ interest rate rules consistently with their assessments of the speed at which economic activity and inflation rebound. PRISM and EDO forecasts display a relatively steeper path for the federal funds rate, starting at 2.7 percent and 2.4 percent in the 2018Q4 and gradually reaching 3.7 percent and 3.6 percent in 2020Q4, respectively. In contrast, the New York Fed model projects a shallower path with the federal funds rate at 2.2 percent in 2018Q4 and increasing to 2.8 percent by 2020Q4. (The Chicago Fed model's projections, 2.4 percent in 2018Q4 and 3.1 percent in 2020Q4, come straight from the Survey of Market Participants, so they contain no new information.) The Tealbook predicts a much steeper path than any of the DSGE models, rising to 4.5 percent by 2020Q4.

The forecasts of the *real* natural rate of interest are higher in 2018. The two extreme forecasts, PRISM and Chicago Fed, increased their forecasts by 30 basis points and 70 basis points respectively. The other two models' forecasts for 2018 are unchanged, so the median forecast remains at 1.2 percent. The strongest forecasts for 2018 and 2020 come from EDO, 1.7 percent and 1.8 percent. The Chicago Fed gives the weakest forecasts for those years, 0.9 percent and 0.7 percent. The intermediate forecasts for those years remain unchanged after rounding. Therefore, the median DSGE forecasts, 1.1 percent and 1.4 percent, are also similar to their values in March.

Finally considering the output gap, three of the four models predict that it will be close to zero by 2020Q4. EDO, the New York Fed, and the Chicago Fed predict 0.0 percent, -0.3 percent, and 0.1 percent for that quarter. However, this convergence comes from a sharp disagreement about the output gap in 2018Q4. Both EDO and the New York Fed forecast this at -0.4 percent, while the Chicago Fed puts this at 2.0 percent. PRISM's output gap projections are much lower

than the others across the forecast horizon, -1.5 percent in 2018Q4 and -0.9 percent in 2020Q4. The Tealbook's forecasts exceed all of the corresponding DSGE projections. Indeed, its 2020Q4 forecast of 2.9 percent sharply contrasts with the median DSGE forecast of -0.2 percent.
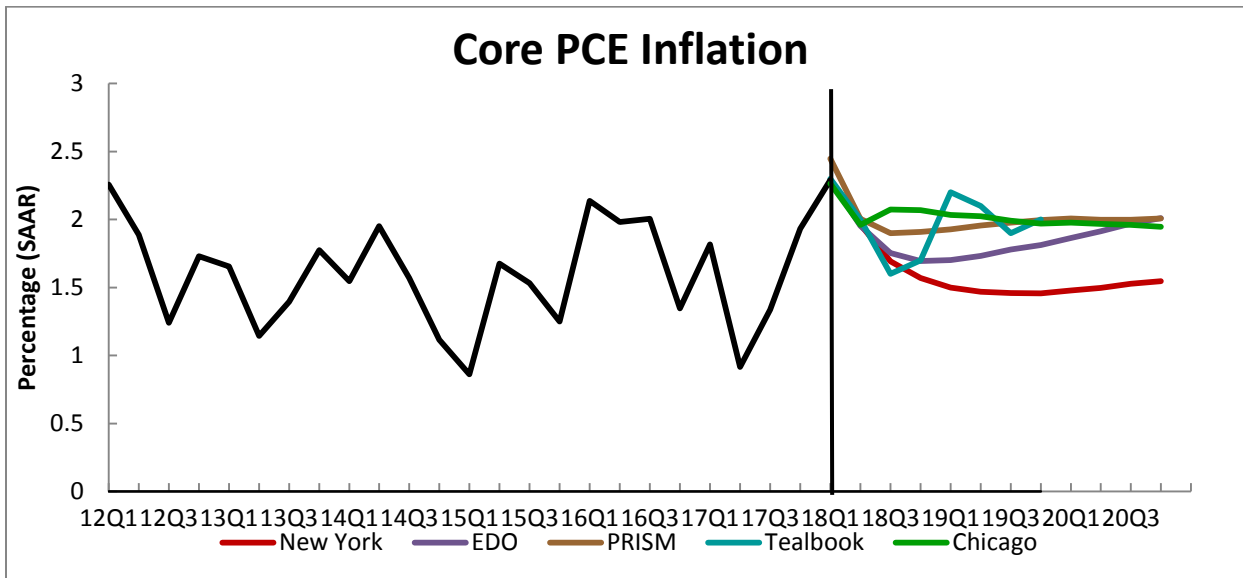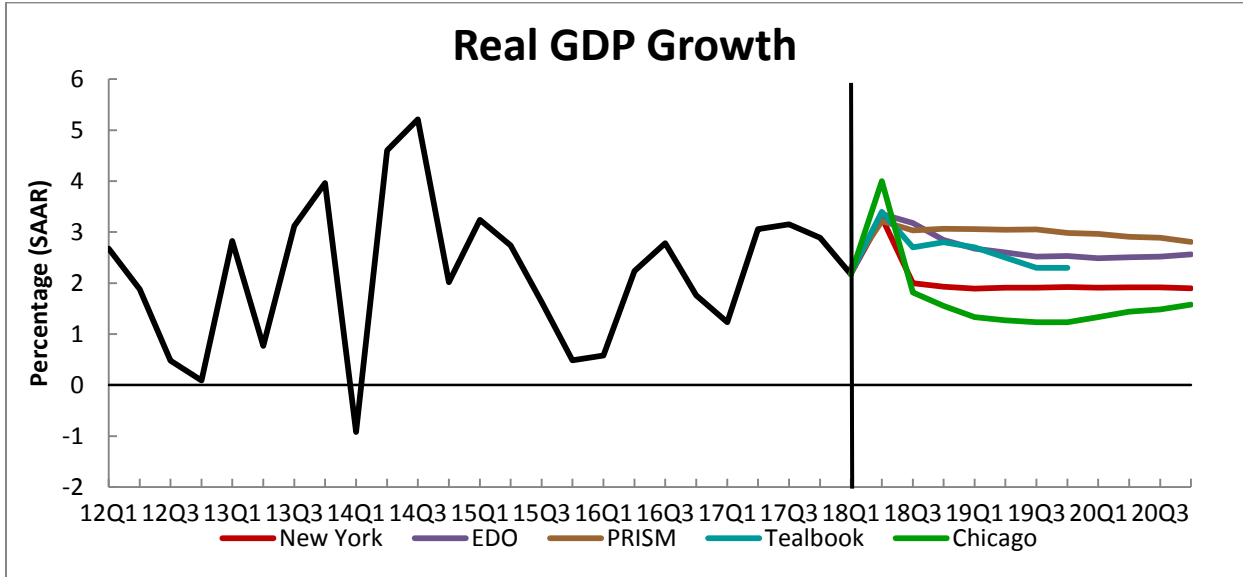
Forecasts

Model	Output Growth (Q4/Q4)					
	2018		**2019**		**2020**	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**2.9**	2.4	**2.6**	2.6	**2.5**	2.7
	(1.8,4.0)	(0.8, 3.9)	**(0.5,4.7)**	(0.5, 4.7)	**(0.4, 4.7)**	(0.6, 4.8)
New York Fed	**2.3**	2.3	**1.9**	2.0	**1.9**	2.1
	(0.8, 3.8)	(0.2, 4.2)	**(-1.0, 4.5)**	(-0.8, 4.7)	**(-0.9, 4.7)**	(-0.8, 4.8)
PRISM - Philadelphia Fed	**2.9**	2.5	**3.1**	3.1	**2.9**	3.0
	(1.5, 4.4)	(0.4, 4.7)	**(-0.3, 6.4)**	(-0.1, 6.7)	**(-0.4, 6.6)**	(-0.5, 6.6)
Chicago Fed	**2.4**	1.8	**1.3**	1.2	**1.5**	1.5
	(0.8, 4.0)	(-0.7, 4.3)	**(-2.4, 4.9)**	(-2.6, 4.9)	**(-2.4, 5.2)**	(-2.3, 5.3)
Median Forecast*	**2.6**	2.4	**2.2**	2.3	**2.2**	2.4
June Tealbook	**2.8**		**2.4**		**1.8**	

Model	Core PCE Inflation (Q4/Q4)					
	2018		**2019**		**2020**	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**1.9**	1.9	**1.8**	1.8	**2.0**	2.0
	(1.6, 2.2)	(1.4, 2.4)	**(0.9, 2.5)**	(1.0, 2.7)	**(1.0, 2.9)**	(1.0, 2.9)
New York Fed	**1.9**	1.8	**1.5**	1.5	**1.5**	1.5
	(1.5, 2.3)	(1.3, 2.4)	**(0.5, 2.4)**	(0.5, 2.5)	**(0.4, 2.6)**	(0.4, 2.7)
PRISM - Philadelphia Fed	**2.1**	1.8	**2.0**	1.9	**2.0**	2.0
	(1.5, 2.6)	(1.0, 2.7)	**(0.5, 3.4)**	(0.4, 3.4)	**(0.5, 3.7)**	(0.3, 3.6)
Chicago Fed	**2.1**	1.9	**2.0**	1.7	**2.0**	1.7
	(1.7, 2.5)	(1.0, 2.6)	**(1. 2, 2.8)**	(0.9, 2.6)	**(1.1, 2.8)**	(0.8, 2.6)
Median Forecast*	**2.0**	1.9	**1.9**	1.8	**2.0**	1.9
June Tealbook	**1.9**		**2.0**		**2.1**	

Model	Federal Funds Rate (Q4)					
	2018		**2019**		**2020**	
	June	March	**June**	March	**June**	March
EDO - Board of Governors	**2.4**	2.4	**3.2**	3.1	**3.6**	3.5
	(1.6, 3.2)	(1.4, 3.4)	**(1.6, 4.9)**	(1.5, 4.7)	**(1.8, 5.5)**	(1.7, 5.4)
New York Fed	**2.2**	2.3	**2.6**	2.7	**2.8**	2.9
	(0.7, 3.7)	(0.9, 3.7)	**(1.0, 4.4)**	(1.0, 4.4)	**(1.1, 4.7)**	(1.1, 4.8)
PRISM - Philadelphia Fed	**2.7**	2.6	**3.4**	3.2	**3.7**	3.6
	(1.8, 3.5)	(1.4, 3.7)	**(1.4, 5.4)**	(0.8, 5.2)	**(1.1, 6.2)**	(1.1, 6.4)
Chicago Fed	**2.4**	2.3	**2.9**	2.9	**3.1**	2.8
	(2.1, 2.7)	(1.8, 2.9)	**(1.6, 4.1)**	(1.4, 4.3)	**(1.2, 5.0)**	(0.8, 4.9)
Median Forecast*	**2.4**	2.4	**3.0**	3.0	**3.3**	3.2
June Tealbook	**2.5**		**3.8**		**4.5**	

Model	Real Natural Rate of Interest r* (Q4)					
	2018		**2019**		**2020**	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**1.5**	1.5	**1.7**	1.5	**1.8**	1.6
	(-3.1, 5.8)	(-3.4, 6.4)	**(-3.1, 6.8)**	(-3.4, 6.5)	**(-3.2, 6.9)**	(-3.5, 6.4)
New York Fed	**1.0**	1.0	**1.3**	1.3	**1.4**	1.4
	(-0.6, 2.6)	(-0.7, 2.6)	**(-0.5, 3.1)**	(-0.6, 3.1)	**(-0.5, 3.2)**	(-0.6, 3.3)
PRISM - Philadelphia Fed	**0.3**	0.0	**1.0**	1.0	**1.4**	1.5
	(-2.2, 3.8)	(-3.1, 2.8)	**(-2.7, 3.9)**	(-2.0, 4.2)	**(-2.0, 4.3)**	(-2.4, 4.2)
Chicago Fed	**2.2**	1.5	**0.9**	0.8	**0.7**	0.5
	(-0.1, 4.5)	(-1.1, 4.2)	**(-2.2, 3.9)**	(-2.3, 3.9)	**(-2.6, 3.9)**	(-2.7, 3.8)
Median Forecast*	**1.2**	1.2	**1.1**	1.2	**1.4**	1.5

Model	Output Gap (Q4)					
	2018		2019		2020	
	June	*March*	June	*March*	June	*March*
EDO - Board of Governors	**-0.4**	-0.6	**-0.1**	-0.4	**0.0**	-0.2
	(-1.2, 0.4)	(-1.6, 0.5)	**(-1.6, 1.4)**	(-2.0, 1.4)	**(-1.9, 1.9)**	(-2.2, 1.8)
New York Fed	**-0.4**	-0.7	**-0.3**	-0.6	**-0.3**	-0.4
	(-2.1, 1.2)	(-2.6, 1.0)	**(-3.1, 2.1)**	(-3.3, 1.9)	**(-3.6, 2.6)**	(-3.8, 2.6)
PRISM - Philadelphia Fed	**-1.5**	-1.3	**-1.1**	-0.8	**-0.9**	-0.6
	(-2.6, -0.3)	(-2.3, 0.0)	**(-2.3, 0.4)**	(-2.3, 0.4)	**(-2.3, 0.7)**	(-2.0, 1.0)
Chicago Fed	**2.0**	1.0	**1.0**	0.0	**0.1**	-0.6
	(1.3, 2.8)	(-0.1, 2.2)	**(-1.1 3.1)**	(-2.3, 2.4)	**(-2.8, 3.0)**	(-3.6, 2.4)
Median Forecast*	**-0.4**	-0.7	**-0.2**	-0.5	**-0.2**	-0.5
June Tealbook	**2.5**		**3.0**		**2.9**	

Real GDP Growth

Core PCE Inflation

Federal Funds Rate

Real Natural Rate

Output Gap
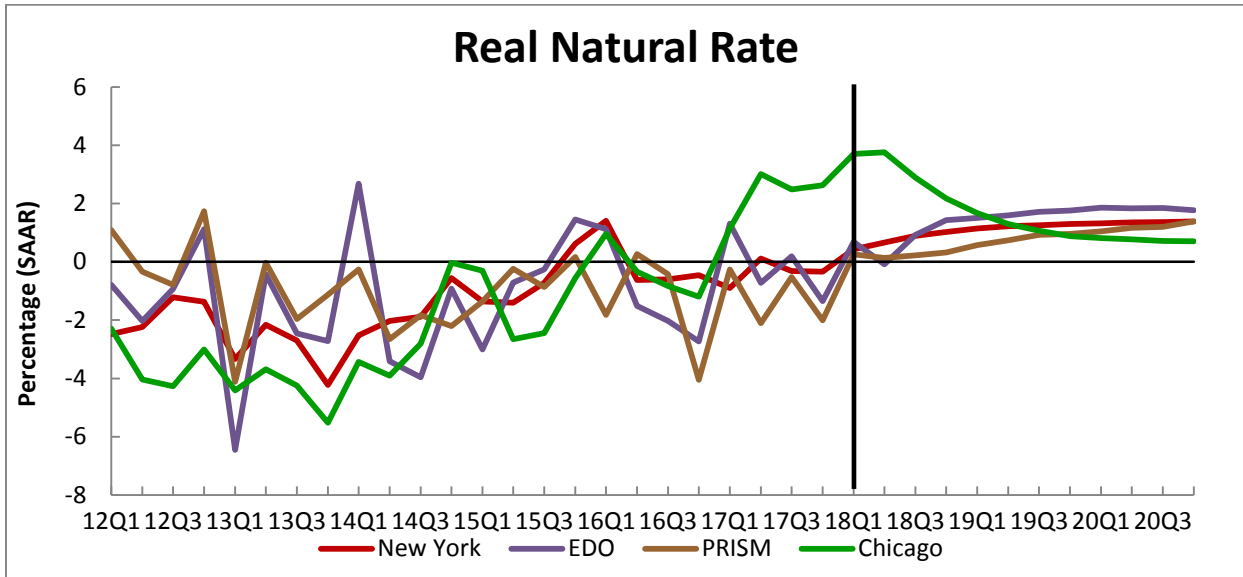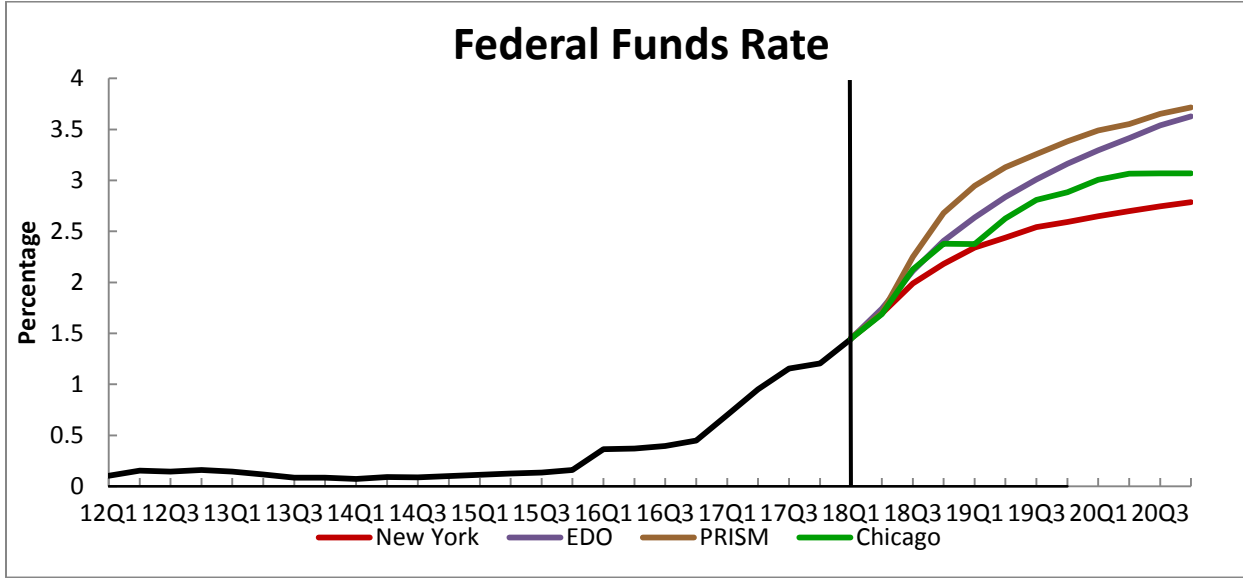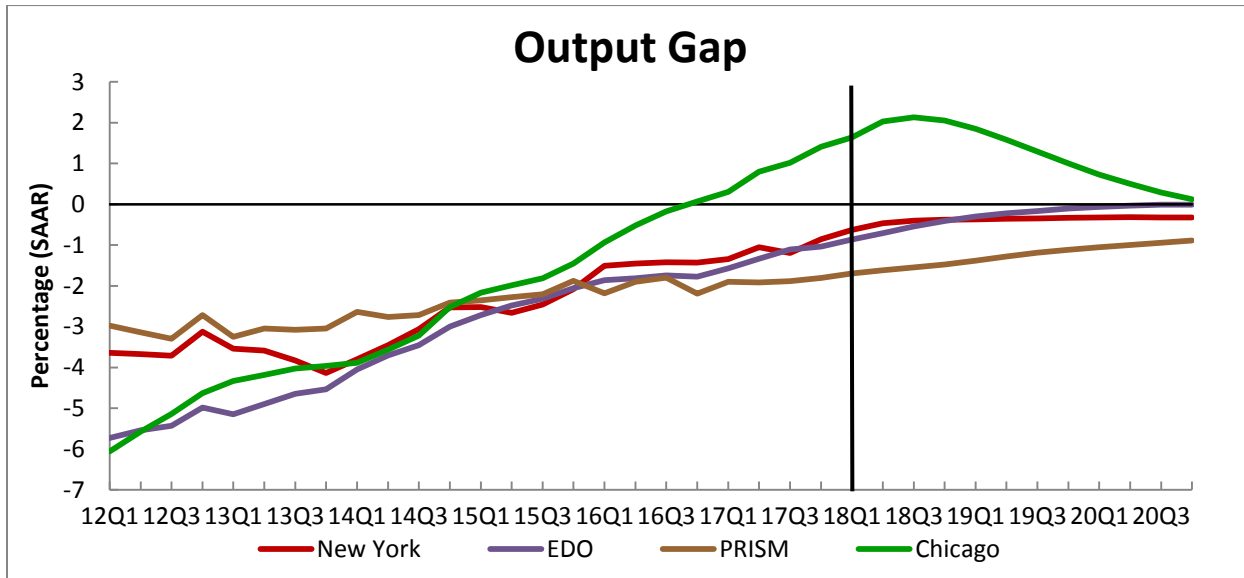
Detailed Descriptions of Individual Model Forecasts

The EDO Model

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

Real GDP growth is about 2.6 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 third quarter of 2020. Below-trend real GDP growth is driven by the slow fading of 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 time period. The persistence of these wage shocks accounts for most of the weakness in inflation over the forecast. By contrast, the rise in inflation at the beginning of 2018 is attributed by the model to transient shocks to the price Phillips curve, which largely dissipate by the first half of 2019.

The output gap is currently estimated to be -0.7 percent, and the economy slowly reaches its full potential by 2020Q4. The real natural rate of interest is estimated to be around 0.9 percent in 2018Q3 and thereafter hovers around 1.7 percent until 2020Q4, 0.4 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 well below those that would have prevailed in the absence of nominal rigidities, and that the investment-related shocks responsible for this condition are likely to dissipate slowly.

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 3.6 percent in 2020Q4. 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.

Compared with the March 2018 projection, the EDO model's forecast of real GDP growth in this round is stronger until the first half of 2019 because of various transitory factors;

thereafter, real GDP growth is only a touch weaker relative to March. Core PCE inflation is, on average, unchanged over the forecast horizon. The output gap has been revised up, on average, 15 basis points over the projection period since March, while the forecast of the real natural rate of interest has been revised up 15 basis points, on average, since March, with a noticeable upward revision in 2017 due to positive revisions to the contribution of TFP growth shocks. The path of the federal funds is a touch higher this round than in March, following the upward revision of the output gap.

The New York Fed Model

The New York Fed model forecasts are obtained using data released through 2018Q1, augmented for 2018Q2 with the New York Fed staff forecasts (as of May 31st) 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 2018Q2 averages up to May 31.

Based on this information, we project real GDP growth of 2.3 percent in 2018 on a Q4/Q4 basis, in line with the March forecast. GDP growth is anticipated to decline to 1.9 percent in 2019 and 2020, slightly below the March forecast of 2.0 percent and 2.1 percent in 2019 and 2020 respectively. Inflation is forecast to be slightly higher in the short term, at 1.9 percent relative to 1.8 percent in the March projection. While inflation in 2018 is close to the FOMC's longer run goal of 2 percent, the model projects that inflation will decline to 1.5 percent in 2019 and 2020 (unchanged from the March projection).

The output gap is projected to be -0.4 percent in 2018, -0.3 percent in 2019 and -0.3 percent in 2020. This represents an improvement relative to the March forecast of the output gap (-0.7 percent, -0.6 percent and -0.4 percent in 2018, 2019 and 2020 respectively), especially in the near term. The forecast for the natural rate of interest is unchanged from March, rising from 1.0 percent in 2018Q4 to 1.4 percent in 2020Q4. The federal funds rate is forecast to be 0.1 percentage points lower than the March projections throughout the forecast horizon: 2.2, 2.6 and 2.8 percent in 2018, 2019 and 2020 respectively. This shallower path translates into approximately two more hikes in 2018, one more in 2019 and another in 2020.

The projections for all the variables are surrounded by significant uncertainty. For instance, the 68 percent posterior probability interval for GDP growth includes negative readings for the

years between 2019 and 2020. In comparison, the posterior probability intervals for inflation are tighter, with their upper bound never exceeding 3 percent throughout the forecast horizon.

As in March, the model explains the above long-run average real GDP growth rate in 2018 with continued improvement in financial conditions, as captured by positive contributions of both the financial and marginal efficiency of investment shocks. Over the medium term however, these factors are offset by lower TFP growth and the gradual withdrawal of monetary accommodation. Sluggish TFP growth also explains, at least in part, the negative output gap over the forecast horizon. The model projects near-target inflation for 2018, driven by a temporary increase in price markups. However, as in March, the model projects below-target inflation in 2019 and 2020, driven by a confluence of several factors. These factors include the lingering effects of the financial headwinds that have hampered the recovery, as well as negative shocks to wage and price markups. Finally, the federal funds rate is projected to remain below its long-run level of 4 percent throughout the forecast horizon owing to persistence in the interest rate rule, weak projected inflation and a persistently negative output gap.

The PRISM Model

The Philadelphia Research Intertemporal Stochastic Model (PRISM) forecast is constructed using data through 2018Q1 that are then supplemented with a 2018Q2 nowcast based on the most recent Macroeconomic Advisors model forecast.

PRISM forecasts that output will grow at a 2.9 percent pace in 2018, up about 0.3 percentage points from the pace posted in 2017. Output growth is projected to be near 3 percent through the end of 2019, and then edge down to 2.8 percent by the end of 2020. PRISM does not explicitly take account of the recent tax reform except to the extent that reform is affecting the underlying data on which the model is estimated. The nowcast pins down real output growth in 2018Q2 at 3.2 percent and core inflation at 2 percent. Core inflation stays about flat at 2 percent over the forecast horizon. The PRISM projection has the funds rate following an estimated policy rule through the forecast horizon: the federal funds rate averages 2.7 percent in 2018Q4 and advances steadily to reach 3.7 percent in 2020Q4. This monetary policy path is little changed from the March projection.

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 0.1 percent in 2018Q2. 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 2020. 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 -1.6 percent in 2018Q2 and shrinks slowly over the next three years to reach -0.9 percent at the end of 2020.

According to PRISM, above trend output growth in 2018Q2 is being driven by shocks to labor supply, investment, and government spending. Partially offsetting these positive contributions are negative effects from shocks to productivity, financial conditions, and monetary policy. Going forward, output growth runs near its steady state value with positive contributions from labor, investment, and government spending shocks largely offset by negative contributions from financial conditions, monetary policy, and productivity shocks. The latter two shocks wane quickly though and the primary drag on output growth in 2019 and 2020 is financial conditions (discount factor shock). Consumption growth (nondurables plus services) runs at a below trend pace in 2018Q2, held down by shocks to TFP, investment and monetary policy. Going forward, consumption growth accelerates modestly as those shocks wane and as the labor and financial markets continue to rebound. However, consumption growth runs at a pace that is slightly below trend over the forecast horizon. Over the near term, shocks to the marginal efficiency of investment make a strong positive contribution to investment growth, which runs at close to its trend pace over the next two years. Offsetting the investment shocks, negative financial shocks act as a brake on investment growth. By the end of 2020, investment growth tapers off to 2 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 2018Q2 nowcast for core PCE inflation is 2 percent. 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 2018Q4 the funds rate averages 2.7 percent, rising to 3.4 percent in 2019Q4 and 3.7 percent in 2020Q4 -- a similar pace of normalization compared to the March 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 2018Q1 supplemented by judgmental Macro Advisers assumptions for 2018Q2 GDP, consumption, investment, core PCE inflation, and core CPI inflation. We included 2018Q2 expected core PCE inflation one-quarter ahead and over the next 10 years using the Second Quarter SPF survey. We use data on expected future funds rates from the Survey of Market Participants to pin down the federal funds rate path for the next 10 quarters. The model rationalizes these expectations with forward guidance shocks. Beginning in 2021Q1, the model's estimated policy rule takes over.

The model projects GDP growth for 2018 of 2.4 percent, which is slightly above its potential, and 1.3 percent in 2019 before rebounding somewhat to 1.5 percent in 2020. The model attributes growth slightly above potential since 2017Q2 to positive and permanent innovations to neutral technology, investment specific technological progress, relatively loose financial conditions, and a high degree of monetary accommodation from forward guidance[2]. The tightening of financial conditions and gradual removal of monetary accommodations decrease expected GDP growth throughout the forecast horizon. This relatively low forecasted GDP growth and the model's uncertainty around the point forecasts at two and three year horizons mean that we cannot rule out a recession during those years.

The model's projection for core PCE inflation in 2018 equals 2.1 percent. This embodies the very strong figures of core PCE and CPI inflation in 2018Q1, at 2.3 and 2.9 percent

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[2] Since we do not have data for the relative price of consumption to investment for 2018Q2, the model infers this value from the remaining observables. We have run alternative simulations plugging other reasonable values of the relative price in 2018Q2; forecasts and shocks decomposition change very little.

respectively. The model interprets this upward revision in inflation partly as coming from temporary factors (i.e. measurement errors) and partly as the results of positive investment specific technical change which has a long lasting effect on inflation. The model explains the weakness in inflation over the past three years with measurement error and shocks to producers' desired markups. This balance of forces generates a trajectory of inflation for 2019 and 2020 at committee's 2 percent target. Moreover, the model's 68 percent coverage intervals reveal little chance of deflation over the forecast horizon.

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 sees a positive output gap over the previous year equal to 1.6 percent in 2018Q1 and 2.0 percent in 2018Q2. It ends the year at 2.0 percent. Thereafter, we project a steady decline throughout 2019 and 2020, so the economy nearly reaches potential output at the end of the forecasting horizon. The natural rate of interest is above its steady-state value and equals 3.7 percent at the first quarter of 2018. It substantially declines thereafter. Its values in 2018Q4, 2019Q4, and 2020Q4 equal 2.2 percent, 0.9 percent, and 0.7 percent.