

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

Date: June 10, 2019
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

June 10, 2019

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¹We thank Thorsten Drautzburg, Catherine O'Donnell, Hess Chung, Sushant Acharya, Rebecca Sarfati, Jonas Fisher, Jeff Campbell, Meiyao Tysinger, and Brie Coellner for their contributions.

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), Philadelphia Fed, 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 2019Q1 and nowcasts for 2019Q2. EDO, the New York Fed model and the Philadelphia Fed model 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 April/May Survey of Market Participants (augmented using developments in OIS markets since the SMP survey date) 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 Tealbook forecasts, as well as the DSGE model forecasts prepared for the March FOMC meeting. The tables and figures also present 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, they report 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 for 2019 rose to 2.5 percent from 1.6 percent in March. This reflects stronger than expected first quarter growth that led to significant upward revisions to the EDO and Chicago Fed forecasts and somewhat smaller upward revisions to the Philadelphia Fed and New York Fed forecasts. The median forecast for 2020 rose 0.3 percentage points to 2.3 percent, while the median forecast for 2021 remains unchanged at 2 percent. The Tealbook forecasts for 2019 and 2020, at 2.0 percent and 2.1 percent, respectively, are close to the median forecasts. The Tealbook has output growth stepping down to 1.7 percent in 2021 from 2.1 percent in 2020, about 0.3 percentage points lower than the median. The Philadelphia Fed model predicts that output growth will rise gradually from 2.5 percent in 2019 to 2.8 percent in 2021. The New York Fed sees real output growth hovering around 1.7 percent over the forecast horizon.

As well, EDO has a relatively flat growth profile, though at a higher level, with real output growth averaging about 2.3 percent over the forecast horizon. The Chicago Fed forecast is more pessimistic, with output growth falling from 2.8 percent in 2019 to 1.4 percent in 2021.

Turning to inflation, the median forecasts for 2020 and 2021 are very close to the committee's 2 percent target and are unchanged from the March projection. However, the inflation forecasts are somewhat weaker for 2019, with the median falling to 1.7 percent from 2 percent in the March round. At the high end, the Philadelphia Fed model forecasts inflation rising from 1.7 percent in 2019 to 2.4 percent in 2021. At the low end, the New York Fed model has inflation at 1.4 percent in 2019 edging up to only 1.5 percent in 2021. The Chicago Fed and EDO forecasts see inflation essentially at the FOMC target in 2020 and 2021. The Tealbook forecast for inflation is just below the 2 percent target for all years over the forecast horizon.

While all of the models predict a rising path for the federal funds rate, their slopes vary substantially. EDO predicts that the federal funds rate will be at 2.9 percent at the end of 2019. The Philadelphia Fed forecast is slightly weaker at 2.6 percent, followed by the New York Fed at 2.4 percent and the Chicago Fed at 2.1 percent. EDO predicts modest further tightening in 2020 and 2021, with the federal funds rate ending those years at 3.4 percent and 3.8 percent. In contrast, tightening proceeds rapidly in the Philadelphia Fed model. Its forecasts for the federal funds rate equal 3.6 and 4.6 percent for the end of 2020 and 2021. On the low end, the New York Fed model predicts one 25 basis point hike sometime over the forecast horizon. The Chicago Fed model has a significant revision to its forecasted funds rate path – now flat at about 2 percent over the forecast horizon, but that reflects the SMP and OIS data rather than rule-based monetary policy. Of the four models' forecasts, that from New York resembles those from the Tealbook most closely.

The four models' estimates of the real natural rate of interest differ substantially from one another. For 2019, the estimates range from a low of 0.1 percent in the Chicago model to high of 2.1 percent in EDO. The New York Fed model and EDO have the real natural rate forecast staying relatively unchanged over the forecast horizon though at different levels (about 2 percent for EDO vs 1.3 percent for New York). In contrast, the Philadelphia forecast shows a significant rise in the natural rate of interest -- on the order of 160 basis points over the forecast horizon. The Chicago Fed forecast shows a more modest rise of about 50 basis points by the end of 2021. Note that the

range of uncertainty surrounding estimates of the natural rate are large. Indeed, for each of the models, the 70 percent confidence intervals incorporate the full range of forecasts.

Estimates of the output gap also show substantial dispersion across the models and the forecasts differ in their view on whether the output gap will widen or shrink over the next three years (as well as whether the gap is positive or negative). As with the natural rate estimates, the uncertainty surrounding gap estimates is high. At the end of 2019, the gap estimates range from a low of -0.4 for the New York Fed to a high of 2.9 percent for Chicago Fed. EDO and the New York Fed model expect the output gap to be slightly negative at the end of 2021. The Philadelphia Fed forecast has the gap closing from 0.9 percent at the end of 2019 to 0.6 percent at the end of 2021. The Chicago Fed estimates a much larger output gap at the end of 2019 that edges down to 1.3 percent by the end of the forecast horizon. The Tealbook forecast estimates the output gap at 1.9 percent at the end of 2019, edging up to 2 percent by the end of 2021.

Forecasts

Model	Output Growth (Q4/Q4)					
	2019		2020		2021	
	June	March	June	March	June	March
EDO - Board of Governors	2.4 (1.4,3.5)	1.5 (0.1,3.0)	2.2 (0.1,4.2)	1.9 (-0.1,4.0)	2.3 (0.2,4.4)	2.3 (0.1,4.4)
New York Fed	1.8 (0.3,3.2)	1.6 (-0.4,3.5)	1.7 (-1.1,4.2)	1.7 (-1.2,4.2)	1.7 (-1.1,4.4)	1.7 (-1.1,4.4)
Philadelphia Fed	2.5 (1.0,4.0)	2.2 (0.1,4.3)	2.7 (0.0,5.6)	2.7 (-0.1,5.5)	2.8 (-0.1,5.8)	2.7 (-0.2,5.7)
Chicago Fed	2.8 (0.7,4.9)	1.3 (-1.9,4.4)	2.4 (-2.3,7.0)	2.1 (-2.6,6.7)	1.4 (-3.4,6.1)	1.8 (-2.9,6.6)
Median Forecast*	2.5	1.6	2.3	2.0	2.0	2.0
June Tealbook	2.0		2.1		1.7	

Model	Core PCE Inflation (Q4/Q4)					
	2019		2020		2021	
	June	March	June	March	June	March
EDO - Board of Governors	1.7 (1.4,2.0)	2.2 (1.7,2.7)	2.0 (1.2,2.8)	2.2 (1.4,3.1)	2.1 (1.2,3.1)	2.2 (1.4,3.1)
New York Fed	1.4 (1.0,1.8)	1.5 (1.0,2.1)	1.4 (0.5,2.3)	1.4 (0.3,2.3)	1.5 (0.4,2.6)	1.4 (0.3,2.6)
Philadelphia Fed	1.7 (1.1,2.3)	2.2 (1.2,3.1)	2.3 (0.6,3.9)	2.4 (0.6,4.1)	2.4 (0.5,4.3)	2.4 (0.4,4.4)
Chicago Fed	1.9 (1.2,2.4)	1.8 (1.3,2.9)	2.1 (1.2,3.0)	2.0 (1.2,2.9)	2.0 (1.0,2.9)	2.0 (1.1,2.9)
Median Forecast*	1.7	2.0	2.1	2.1	2.1	2.1
June Tealbook	1.8		1.9		1.9	

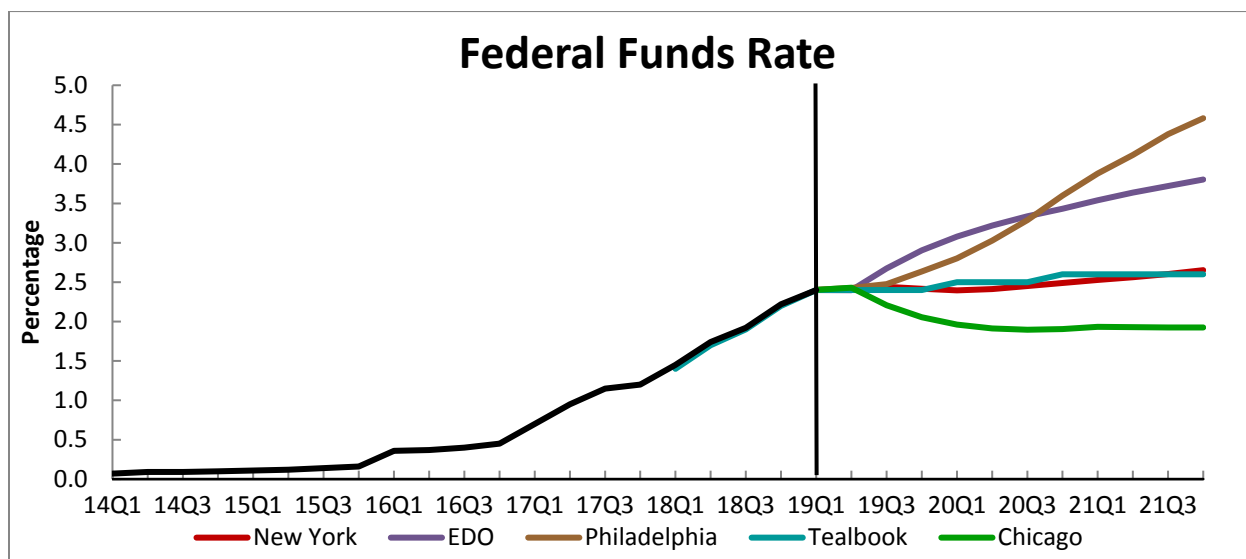
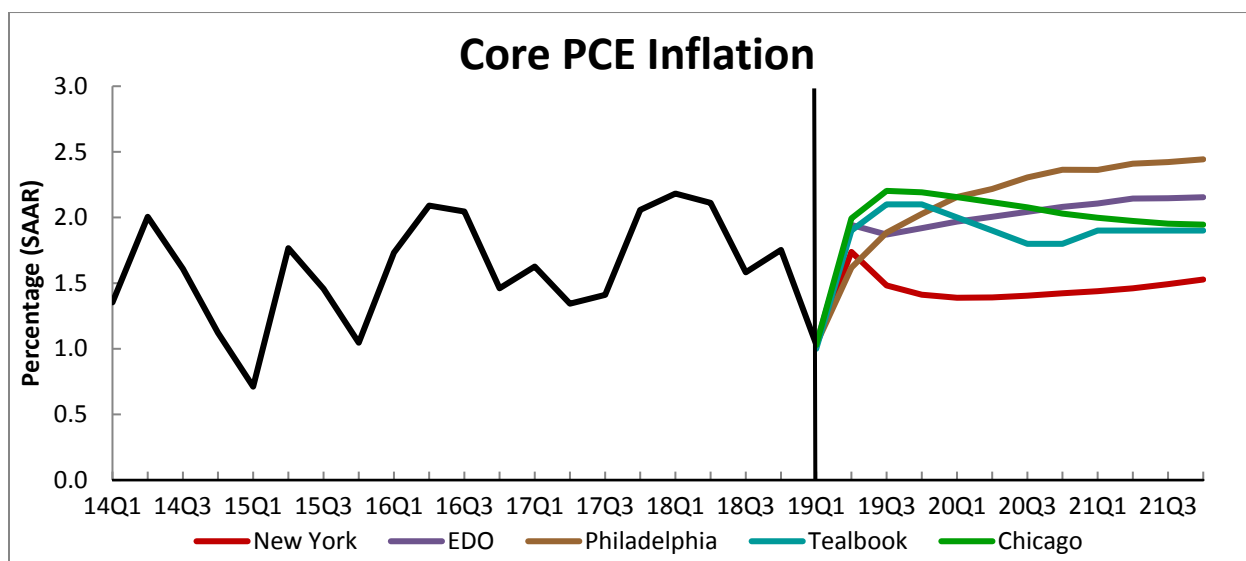
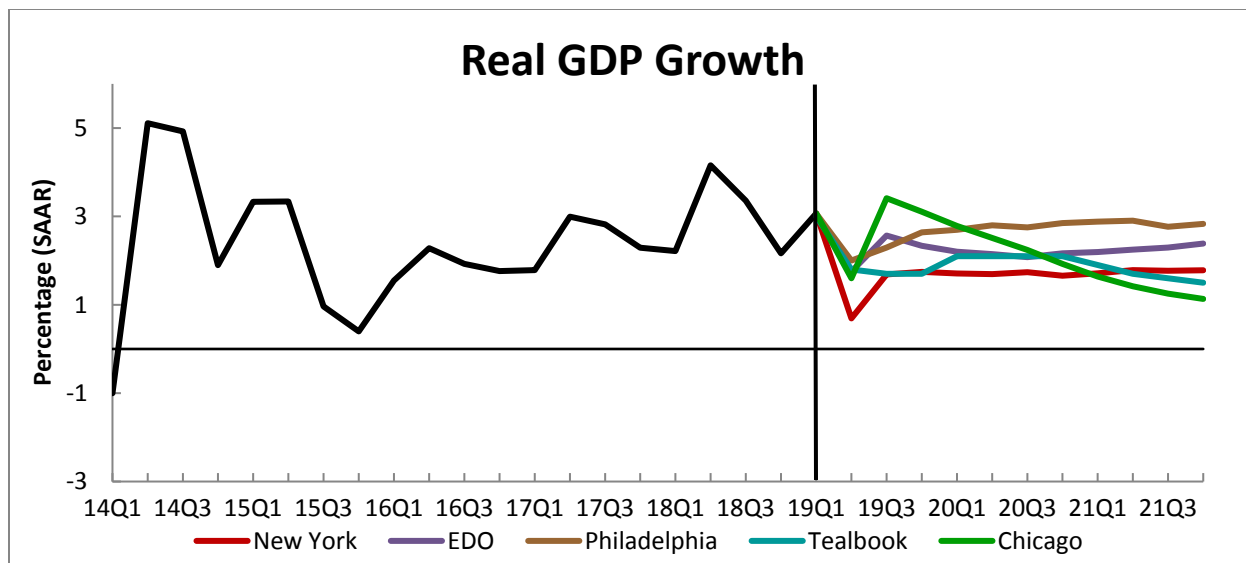
Model	Federal Funds Rate (Q4)					
	2019		2020		2021	
	June	March	June	March	June	March
EDO - Board of Governors	2.9 (2.1,3.7)	3.1 (2.1,4.2)	3.4 (1.9,5.0)	3.5 (1.9,5.2)	3.8 (2.0,5.6)	3.7 (1.9,5.6)
New York Fed	2.4 (0.9,3.9)	2.3 (0.7,3.9)	2.5 (0.9,4.3)	2.4 (0.7,4.2)	2.7 (1.0,4.5)	2.5 (0.8,4.5)
Philadelphia Fed	2.6 (1.2,4.1)	2.9 (0.9,4.8)	3.6 (0.1,7.0)	4.0 (0.1,8.0)	4.6 (0.0,9.1)	4.8 (0.1,9.5)
Chicago Fed	2.1 (1.8,2.4)	2.8 (2.3,3.4)	1.9 (0.6,3.2)	2.9 (1.4,4.4)	1.9 (-0.1,4.0)	3.0 (0.8,5.2)
Median Forecast*	2.5	2.9	3.0	3.2	3.2	3.4
June Tealbook	2.4		2.6		2.6	

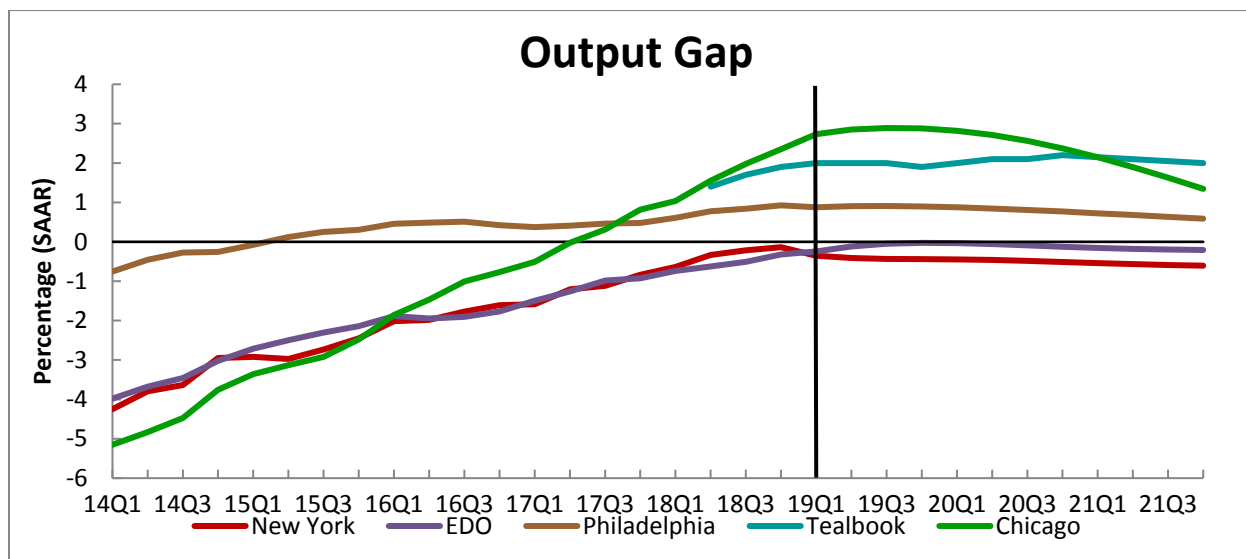
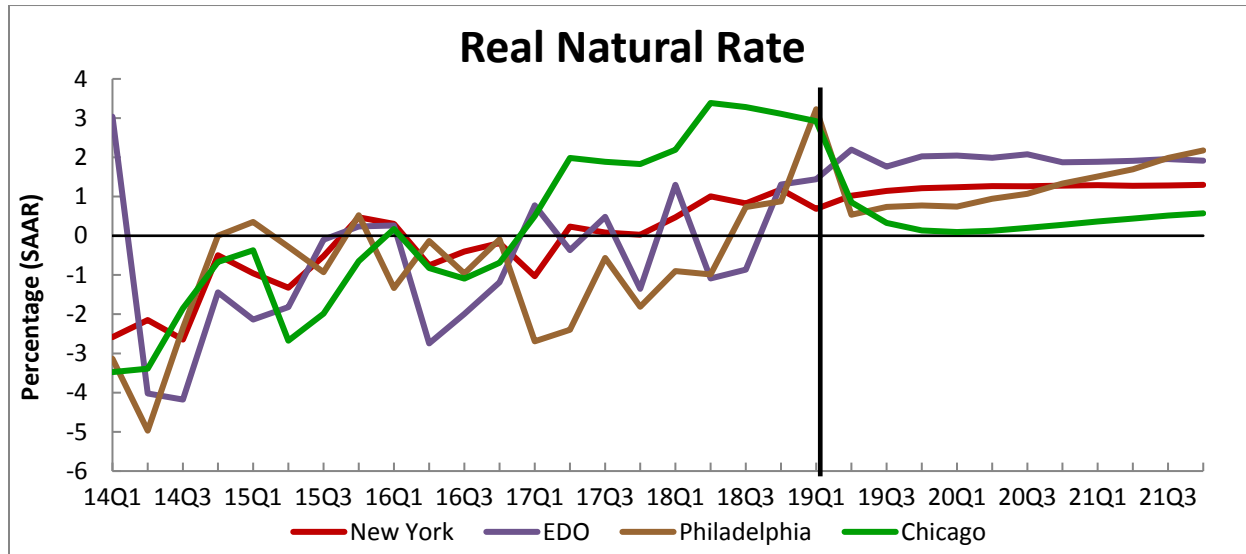
Model	Real Natural Rate of Interest r^* (Q4)					
	2019		2020		2021	
	June	March	June	March	June	March
EDO - Board of Governors	2.1 (-2.6,6.7)	1.8 (-3.1,6.5)	1.9 (-3.1,6.7)	1.6 (-3.4,6.5)	2.0 (-3.2,6.9)	1.6 (-3.5,6.4)
New York Fed	1.2 (-0.4,2.8)	1.3 (-0.5,2.9)	1.3 (-0.5,3.1)	1.3 (-0.6,3.1)	1.3 (-0.5,3.2)	1.2 (-0.7,3.2)
Philadelphia Fed	0.8 (-2.3,3.8)	1.2 (-2.2,4.6)	1.3 (-3.1,5.7)	1.7 (-3.0,6.5)	2.2 (-3.1,7.4)	2.4 (-2.9,7.8)
Chicago Fed	0.1 (-2.1,2.4)	0.2 (-2.4,2.8)	0.3 (-2.8,3.3)	0.6 (-2.6,3.7)	0.6 (-2.7,3.9)	0.7 (-2.7,4.1)
Median Forecast*	1.0	1.2	1.3	1.4	1.6	1.4

Model	Output Gap (Q4)					
	2019		2020		2021	
	June	March	June	March	June	March
EDO - Board of Governors	0.0 (-0.8,0.8)	-0.2 (-1.3,0.8)	-0.1 (-1.7,1.4)	-0.5 (-2.2,1.2)	-0.2 (-2.1,1.7)	-0.6 (-2.6,1.4)
New York Fed	-0.4 (-2.1,1.2)	-0.5 (-2.5,1.4)	-0.5 (-3.2,1.8)	-0.6 (-3.5,1.9)	-0.6 (-3.9,2.3)	-0.7 (-4.4,2.2)
Philadelphia Fed	0.9 (0.6,1.2)	1.0 (0.6,1.5)	0.8 (0.0,1.5)	0.8 (0.0,1.6)	0.6 (-0.4,1.6)	0.5 (-0.5,1.6)
Chicago Fed	2.9 (2.1,3.7)	0.5 (-0.8,1.7)	2.4 (0.2,4.6)	0.1 (-2.3,2.6)	1.3 (-1.6,4.3)	-0.2 (-3.2,2.9)
Median Forecast*	0.4	0.1	0.3	-0.2	0.2	-0.4
June Tealbook	1.9		2.2		2.0	

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 first quarter of 2019 and on a preliminary Tealbook forecast for the second quarter of 2019.

Real GDP growth is $2\frac{1}{4}$ percent, on average, over the projection horizon, about equal to the average growth rate of potential output. The inflation rate is near 2 percent from the current quarter until the end of 2020, before rising to 2.1 percent in 2021.

Potential GDP growth is about $2\frac{1}{4}$ percent over the projection horizon, held down below trend by the slow fading of adverse risk premium shocks. The output gap is currently estimated to be negative 0.1 percent and is projected to narrow somewhat over the remainder of 2019 before widening again to negative 0.2 percent by the end of 2021. The real natural rate of interest—estimated to be 2.2 percent in the second quarter of 2019—is projected to remain around 2 percent through the end of the forecast, modestly below its long-run value of 2.2 percent. Both the output gap and natural rate of interest remain slightly, but stubbornly, below their long-run values as a result of persistent adverse shocks to investment over the past few years, which have depressed the current capital stock below the level that would have prevailed in the absence of nominal rigidities and which are expected to restrain investment spending for quite a while in the forecast.

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 $3\frac{3}{4}$ percent by the end of 2021, a bit below its long-run value.

The data on 2019:Q1 GDP growth were much stronger than the EDO model had projected in March, and the model accounts for about half of the surprise with favorable shocks to total factor productivity (TFP) and risk premiums. Accordingly, the EDO model's forecast of real GDP growth has revised up this round, with the data on growth in the first half of the year responsible for the bulk of the revision to 2019 growth and the effects of higher TFP driving the stronger growth forecast for 2020. By contrast, recent data on PCE inflation in the first quarter of 2019 were much weaker than the EDO model had projected in March, and the model has carried forward some of that weakness into 2020, mostly as a consequence of lower wage

markups. Both the output gap and the natural rate of interest have also revised up, particularly toward the end of the forecast horizon. The forecast for the federal funds rate in 2020 has revised down 0.1 percentage point, as the contribution to the funds rate from lower inflation in that year dominates the effects of the positive revisions to the output gap. By 2021, however, the current forecast of inflation is close to the March projection, while the output gap is almost $\frac{1}{2}$ percentage point narrower and, consequently, the federal funds rate ends 2021 slightly higher than shown in March.

The NY Fed Model

The New York Fed model forecasts are obtained using data released through 2019Q1, augmented for 2019Q2 with the New York Fed staff forecasts (as of May 28) for real GDP growth and core PCE inflation, and with values of the federal funds rate, the 10-year Treasury yield and the spread between Baa corporate bonds and 10-year Treasury yields based on 2019Q2 averages up to May 31.

The model projects real GDP growth of 1.8 percent in 2019 on a Q4/Q4 basis, slightly above the March forecast of 1.6 percent. This revision largely reflects the fact that realized GDP growth for 2019Q1 (3.1 percent) was higher than the March New York Fed staff forecast of 1.4 percent. The model interprets this as temporarily higher productivity which is expected to dissipate by the end of the year. This is reflected in the fact that the forecast for GDP growth of 1.7 percent in both 2020 and 2021 remains unchanged since March. The model's projections for inflation remain broadly similar to its projections in March. Inflation is forecast to be 1.4 percent in 2019, 0.1 percentage points lower than the forecast in March. The model projects inflation will remain steady at 1.4 percent in 2020 with a slight uptick to 1.5 percent in 2021.

The model implied output gap is estimated to be smaller in 2019 than projected in March: -0.4 percent compared with -0.5 percent. The gap is expected to widen to -0.5 percent in 2020 and -0.6 percent in 2021. Compared to the March estimate, the natural rate of interest is projected to be slightly lower at 1.2 percent in 2019 and is expected to rise slightly to 1.3 percent in both 2020 and 2021. As aforementioned, this is due to the temporarily higher productivity. The Federal Funds Rate is forecast to have a slightly steeper path than anticipated in March, reaching 2.7 percent in 2021 (up from the corresponding March forecast of 2.5 percent) from the current level of 2.4 percent.

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 2020 and 2021. In comparison, the posterior probability intervals for inflation are tighter, with their upper bound well below 3 percent throughout the forecast horizon.

The model attributes the slowdown in real GDP growth, relative to the above average growth in 2018, to the abatement of the favorable financial conditions experienced in 2018 and to a decline in productivity. Over the medium term, weaker productivity and the gradual withdrawal of monetary accommodation act as a drag on growth. The model projects a persistent decline in inflation driven primarily by negative shocks to wage and price markups, but also by 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 Philadelphia Fed Model

The Philadelphia forecast is constructed using data through 2019Q1 that are then supplemented with a 2019Q2 current-quarter forecast based on staff judgement. For 2019Q2, real GDP growth is pegged at 2 percent, core inflation is at 1.6 percent, and the federal funds rate is at 2.4 percent. With this nowcast and the historical data in hand, the Philadelphia model estimates the output gap at 0.9 percent and the natural real rate of interest at 0.5 percent in 2019Q2.

Looking ahead, real GDP growth is expected at 2.5 percent in 2019, rising to 2.7 percent over 2020-2021. Thus, output growth is expected to be largely above our estimate of trend (2.4 percent) over the forecast horizon. With output growing at an above-trend pace, inflation rises from 1.7 percent in 2019 to 2.4 percent in 2021. Responding to above-target inflation, the federal funds rate rises from 2.6 percent in 2019Q4 to 4.6 percent in 2021Q4.

The natural rate of interest – the rate of interest that would prevail if wages and prices were full flexible – is expected to rise from 0.5 percent in 2019Q2 to 1.3 percent at the end of 2020 and 2.2 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 gap stands at 0.9 percent in 2019Q1, and falls modestly over the forecast horizon – to 0.6 percent by 2021Q4.

According to the Philadelphia model, the slowdown in real output growth in 2019Q1 is due to negative contributions from shocks to TFP, the labor market, and investment that offset a positive contribution from markup and government spending shocks. Growth moves up to 2.3 percent in the third quarter, and rises to a peak of 2.9 percent in mid-2021. Underlying the growth acceleration is the waning of TFP and negative preference shocks realized in 2019Q2, as well as a strong positive contribution from a rebound in investment. The model sees consumption growth (nondurables and services) as significantly below trend, on average, over the next two years. But consumption growth rises gradually over the forecast horizon to reach a 2 percent pace by the end of 2022. Investment growth, however, is expected to be at an above-trend pace over the next three years driven largely by contributions from investment shocks and, over the near term, markup shocks.

Core inflation is expected to run at a pace above the FOMC target over the forecast horizon rising gradually to reach a peak of 2.4 percent at the end of 2021. Positive contribution to inflation from TFP, markup, and discount factor shocks are only partly offset by negative contributions from investment, government spending, and labor shocks.

The forecast is implemented with a rule-based federal funds rate path that sets the funds rate based on the lagged interest rate, inflation, and output growth. By 2019Q4 the funds rate averages 2.6 percent and rises steadily to 4.6 percent at the end of 2021. The model currently has the equilibrium federal funds calibrated to 3.75 percent. Over the medium term, negative contribution from investment and government spending shocks pull the funds rate well below its longer-run value. As these shocks wane, the funds rate rises and so moderates the rise in inflation over the medium term.

The Chicago Fed Model

The Chicago Fed's DSGE model forecast is constructed using data through 2019Q1 supplemented by judgmental assumptions for 2019Q2 GDP, consumption, investment based on Macro Advisors and Chicago Fed projections. We included 2019Q2 expected inflation, both one-quarter ahead and over the next 10 years, taken from the Second Quarter SPF survey. We used data on expected future funds rates from the April 22 Survey of Market Participants augmented

with OIS rate changes since then to determine the federal funds rate path for the next 10 quarters.² The model rationalizes these expectations with forward guidance shocks. Beginning in 2022Q1, the model's estimated policy rule takes over.

The model sees strong growth for 2019. This mostly embodies the very strong data in hand from the first quarter of 2019 and solid growth projections for the second half of 2019 (i.e. 3.4% for 2019Q3 and 3.1% for 2019Q4), which generates an annual Q4/Q4 GDP growth rate of 2.8 percent, one .8 percent above potential. The model rationalizes the plugged weak and below potential GDP growth for the second quarter of 2019 (1.6%) with transitory shocks (e.g. the GDP residual). This is due to the fact that the plugged consumption and investment numbers are relatively strong. The model sees growth above potential also in 2020, with an annual GDP growth forecast at 2.4%. Eventually, expected GDP growth declines below potential in 2021. The strong incoming data for 2019Q1 (coupled with weak PCE inflation data, see below) leads the model to infer strong technological improvements. Their lingering effects lift our GDP forecast for the current and the following year and tend to disappear in 2021. The removal of monetary accommodations contributes to decrease expected GDP growth towards the end of our forecast horizon. This round's forecast represents a substantial improvement over the one we presented in the previous DSGE memo where we were projecting GDP growth at 1.3% for 2019.

Our forecast for Q4/Q4 core PCE inflation is below target in 2019 (e.g. 15 bps). This is mostly due to the weak 2019Q1 (and 2018Q4) data. The model interprets this deviation from target as temporary, e.g. mostly driven by markup shocks. As a consequence, inflation is forecasted to revert back to target relatively quickly and we do not foresee subdued inflation dynamics for the coming years. In particular, inflation equals 2.1% in 2020 and 2% in 2021. Overall, the model suggests that inflation will be close to the FOMC's target in the 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 2019 through 2021 of 2.9 percent, 2.4 percent and 1.4 percent. These gaps are substantially larger than the analogous forecasts we reported in the previous DSGE memo. Since our growth forecasts are also stronger and driven by technology shocks, we conclude that recent economic strength has arisen from

² 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 April 22 through June 3.

growth in potential output more than from potentially inflationary output gaps. We forecast the (real) natural rate of interest at the end of the year for 2018 through 2021 to equal 0.1 percent, 0.3 percent and 0.6 percent. (The long-run – 5 year ahead - natural rate equals 0.86 percent.)