BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

FOMC SECRETARIAT

Date: June 1, 2020

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 1, 2020

Marco Del Negro[1]

Federal Reserve Bank of New York

[1]I thank Jonas Arias, Hess Chung, Filippo Ferroni, Jonas Fisher, Shigeru Fujita, Ethan Matlin, Leonardo Melosi, Keith Sill, and especially William Chen 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), New York Fed, Philadelphia 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 COVID-19 shock presented the DSGE models involved in this exercise with a daunting challenge: forecasting the effects of an extremely large shock which was never observed before, at least in the sample over which these models have been estimated.

The models faced this challenge in a variety of ways. They all made heavy use of external information. This information concerned: 1) the impact of the shock on economic activity in the current quarter, which the models inferred from judgmental nowcasts; 2) the degree of persistence of the shock itself and of its effects on macroeconomic variables, which the models incorporated by relying on judgmental point forecasts or probabilistic surveys such as the Survey of Professional Forecasters; 3) the response of monetary policy to the shock, which was captured using either market-based or survey expectations for the federal funds rate. The approaches used for integrating this external information, and the data sources, vary across models and are described more in detail later in the memo.

All the models also made sure to reflect the elevated degree of uncertainty surrounding the forecasts, stemming from the fact that little is known about the possible channels of transmission of the shock, or the likelihood of its recurrence (i.e., future waves of contagion). The various models calibrated the degree of uncertainty either in an *ad hoc* way, or using explicitly quantitative benchmarks such as, again, probabilistic surveys.

Finally, some of the DSGEs (e.g., the Chicago and the New York Fed models) introduced new shocks with the explicit purpose of modeling the effect of the COVID-19 related disruptions on the economy. In those cases the modelers believed that the existing set of shocks, whose stochastic properties were estimated using a sample that did not contain disturbances like COVID-19, were not adequately capable of capturing the size and persistence of the effects.

The current point forecasts for real GDP growth, core PCE inflation, and the federal funds rate, as well as the 68 percent probability bands, are displayed in the table and figures at the end of this summary section. 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.

The likely devastating impact of the COVID-19 shock on economic activity is apparent from the range of the Q4/Q4 GDP growth forecasts for the current year, which goes from a pessimistic -12.4 percent (Chicago) to a relatively optimistic -3.1 percent (PRISM). [2] The median of the point forecasts across models is -4.8 percent, above the June Tealbook forecast of -7.1 percent. In the March memo some of the models had made a first timid attempt to incorporate the impact of the COVID-19 shock, but of course the size of the forecast revision is exceptional: the March median forecast was 1.7 percent. The uncertainty surrounding these point prediction is very large: for EDO for instance the 68 percent bands range from -9.5 to -0.2 percent. For the other models, uncertainty is not as large, but still very elevated.

All the models predict a rebound of GDP in 2021, although the extent varies across models with EDO being more optimistic (8.4 percent) and the other models more subdued (2 to 4 percent). The median of the point forecasts for Q4/Q4 2021 GDP growth across models is 3.0 percent, below the June Tealbook prediction of 6.7 percent. Again, uncertainty is very large as the 68 percent coverage intervals include negative growth for three out of four models. For all the models, growth in 2022 has returned closer to steady state.

In terms of inflation forecasts, all models agree that the COVID-19 shock will push inflation down, farther away from the FOMC's long run goal, and below the March projections. Core PCE inflation forecasts for 2020 range from almost zero to 1.5 percent. Inflation remains subdued throughout the forecast horizon, with point forecasts in the 0.5 to 1.8 interval in 2021 and 2020. The median of the core inflation predictions across models are 0.8, 1.1, and 1.4 percent for 2020, 2021, and 2022, respectively. These values are 20 to 30 basis points below the Tealbook forecasts throughout the forecast horizon. Unlike for output growth, uncertainty about inflation did not increase much from March to June, if at all (we should note that the Philadelphia model conditions on judgmental inflation projections through the end of the current year, so there is no uncertainty associated with the 2020 forecasts). For all models the chances of deflation are rather negligible,

[2] Note that EDO reports the median forecasts while all other models report the mean.

in spite of the massive decline in economic activity. This is largely because all DSGEs feature a rather flat Phillips curve.

Forecasts for the federal funds rate are not particularly informative as all models condition on either market or survey expectations at least through the end of 2021. The two models that do not condition throughout the forecast horizon, EDO and the NY Fed model, see the federal funds rate rising to about 1 percent by the end of 2022.

For all models the natural rate of interest falls by the end of 2020, and in some cases quite dramatically. The point estimates stretch from -22 percent (Chicago Fed) to -3.3 percent (NY Fed). The projected decline in the natural rate of interest, along with the response of inflation, is in line with the fact that these DSGEs view the COVID-19 shock as mainly a demand shock. The uncertainty concerning the natural rate of interest projections is also very large however with the 68 percent bands including zero for at least one model (EDO). Over the forecast horizon, the natural rate of interest reverts to levels that are close to zero for all models. The June projections of the natural rate of interest for 2022 are 1 to 2 percent below the March forecasts, with the exception of the Chicago Fed DSGE for which the forecast rises slightly in 2022 relative to March.

Finally, all models see a widening of the output gap in the current year, with actual output being from 6.3 to 2.1 percent below natural output. For all but one model, the gap remains negative throughout the forecast horizon. EDO is the exception, in that its gap rises to 5.7 percent in 2021 and remains positive in 2022. The median of the point forecasts of the gap across models is not far from the June Tealbook forecast for 2020 and 2021 (-5.0 and -1.0, respectively), but is still negative in 2022 (-2.0 percent) while the Tealbook's gap is by then slightly positive.

Forecasts

Model	Output Growth (Q4/Q4)					
	2020		2021		2022	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**-3.3 (-9.5, -0.2)**	*1.8 (0.2, 3.3)*	**8.4 (3.1, 14.2)**	*1.8 (-0.3, 3.8)*	**0.4 (-1.9, 2.7)**	*2.2 (0.1, 4.3)*
New York Fed	**-6.2 (-9.4, -4.0)**	*1.4 (-0.5, 3.4)*	**2.1 (-1.5, 4.2)**	*1.7 (-0.9, 4.4)*	**0.8 (-2.1, 3.4)**	*1.9 (-0.7, 4.6)*
PRISM - Philadelphia Fed	**-3.1 (-7.7, -1.6)**	*2.2 (0.3, 4.1)*	**2.2 (-1.8, 6.2)**	*2.7 (0.2, 5.3)*	**3.0 (-0.0, 6.1)**	*2.5 (-0.1, 5.2)*
Chicago Fed	**-12.4 (-14.4, -10.4)**	*1.5 (-0.5, 3.5)*	**3.9 (-0.7, 8.4)**	*2.7 (-1.9, 7.3)*	**0.4 (-4.3, 5.1)**	*1.6 (-3.1, 6.3)*
Median Forecast*	**-4.8**	*1.7*	**3.0**	*2.3*	**0.6**	*2.1*
June Tealbook	**-7.1**		**6.7**		**3.6**	

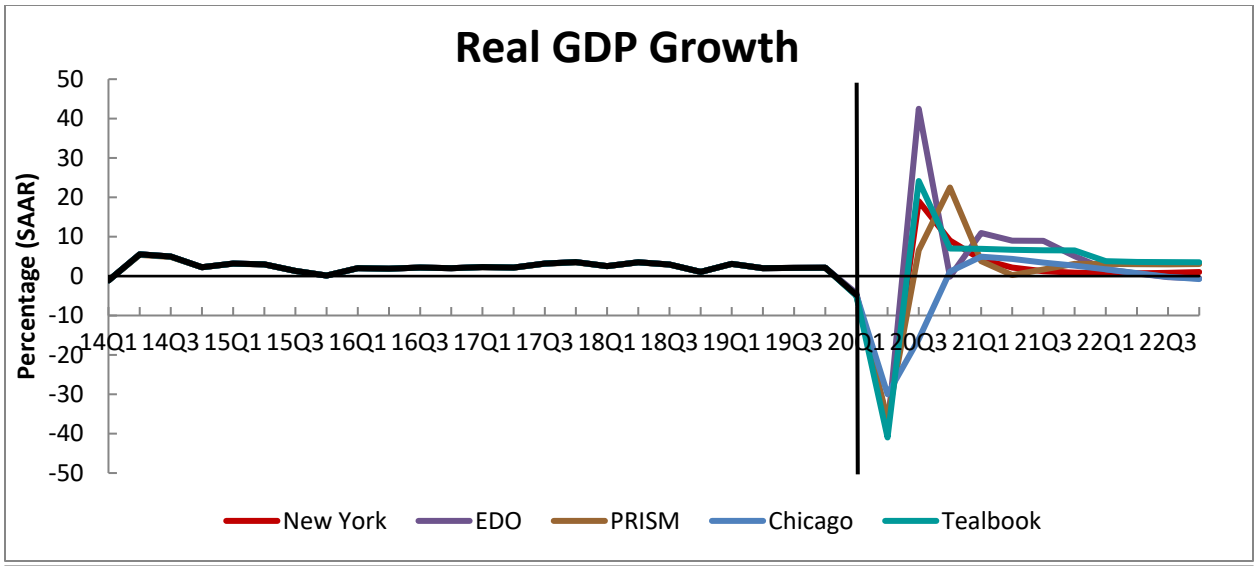
Model	Core PCE Inflation (Q4/Q4)					
	2020		2021		2022	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**0.1 (-0.2, 0.5)**	*1.9 (1.5, 2.4)*	**1.0 (0.1, 1.9)**	*2.3 (1.5, 3.2)*	**1.6 (0.6, 2.7)**	*2.4 (1.4, 3.3)*
New York Fed	**1.5 (1.1, 1.9)**	*1.5 (1.0, 2.1)*	**1.1 (0.1, 2.0)**	*1.4 (0.4, 2.4)*	**1.1 (-0.0, 2.2)**	*1.4 (0.3, 2.6)*
PRISM - Philadelphia Fed	**1.2 (1.2, 1.2)**	*1.7 (0.8, 2.5)*	**0.6 (-0.2, 1.4)**	*2.1 (0.6, 3.6)*	**0.5 (-0.4, 1.4)**	*2.2 (0.5, 3.9)*
Chicago Fed	**0.3 (-0.3, 0.9)**	*1.9 (1.3, 3.6)*	**1.8 (0.6, 3.0)**	*2.3 (1.1, 3.5)*	**1.6 (0.4, 2.9)**	*2.1 (0.9, 3.3)*
Median Forecast*	**0.8**	*1.8*	**1.1**	*2.2*	**1.4**	*2.2*
June Tealbook	**1.1**		**1.6**		**1.7**	

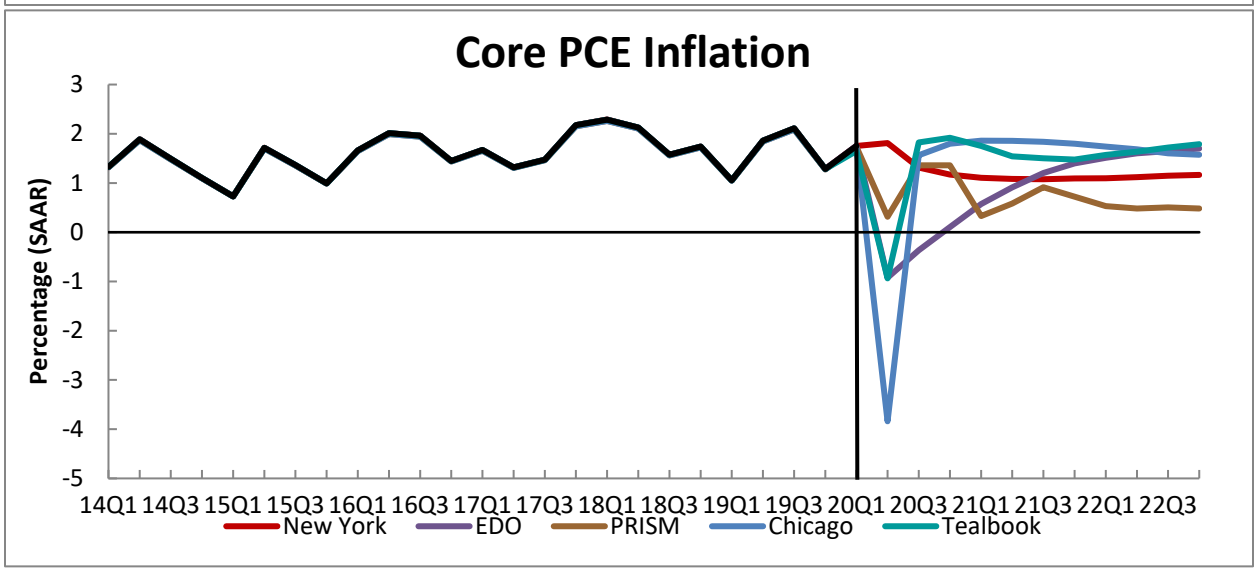
Model	Federal Funds Rate (Q4)					
	2020		2021		2022	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**0.1** **(0.1, 0.1)**	*2.5* *(1.4, 3.5)*	**0.1** **(0.1, 0.1)**	*3.3* *(1.7,5.0)*	**1.2** **(0.2, 2.4)**	*3.8* *(1.9, 5.7)*
New York Fed	**0.1** **(0.0, 1.2)**	*1.7* *(0.2, 3.3)*	**0.1** **(0.0, 1.8)**	*2.3* *(0.5,4.1)*	**1.1** **(0.1, 3.1)**	*2.6* *(0.7, 4.5)*
PRISM - Philadelphia Fed	**0.1** **(0.1, 0.1)**	*1.2* *(-0.8, 3.2)*	**0.1** **(0.1, 0.1)**	*2.2* *(-1.5, 5.9)*	**0.1** **(0.1, 0.1)**	*2.9* *(-1.4, 7.2)*
Chicago Fed	**0.1** **(-0.2, 0.4)**	*0.6* *(0.3, 1.0)*	**0.1** **(-1.1, 1.4)**	*0.6* *(-0.7,1.9)*	**0.1** **(-1.9, 2.1)**	*1.0* *(-1.0, 2.9)*
Median Forecast*	**0.1**	*1.5*	**0.1**	*2.3*	**0.6**	*2.8*
June Tealbook	**0.1**		**0.1**		**0.1**	

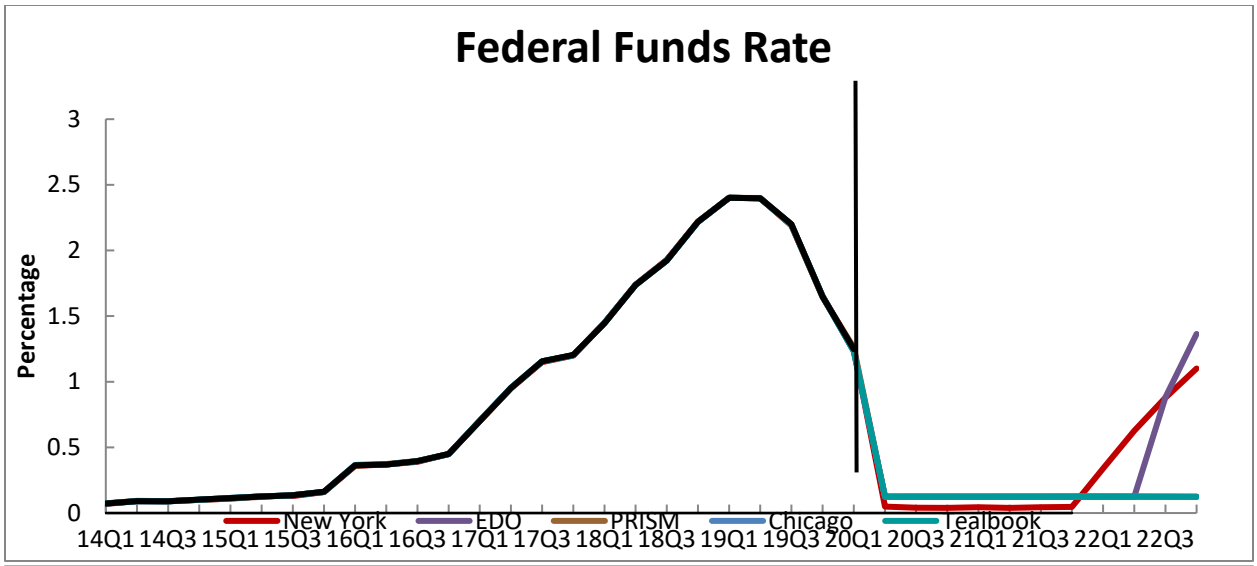
Model	Real Natural Rate of Interest r* (Q4)					
	2020		2021		2022	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**-10.8** **(-34.4, 7.8)**	*1.5* *(-3.4, 6.3)*	**0.2** **(--6.4, 10.0)**	*1.8* *(-3.3, 6.8)*	**-0.1** **(-5.1, 4.8)**	*1.8* *(-3.5, 7.0)*
New York Fed	**-3.3** **(-4.9, -1.8)**	*0.7* *(-0.7, 2.2)*	**-0.3** **(-1.8, 1.3)**	*1.0* *(-0.6, 2.6)*	**0.2** **(-1.4, 1.9)**	*1.1* *(-0.5, 2.8)*
PRISM - Philadelphia Fed	**-20.5** **(-35.2, -5.7)**	*-0.2* *(-3.3, 2.9)*	**0.7** **(-7.3, 8.6)**	*1.1* *(-3.1, 5.3)*	**0.4** **(-5.5, 6.2)**	*1.9* *(-2.8, 6.7)*
Chicago Fed	**-22.0** **(-24.2, -19.7)**	*-2.4* *(-4.7, -0.2)*	**-0.6** **(-3.7, 2.4)**	*-1.2* *(-4.3, 1.9)*	**0.9** **(-2.4, 4.2)**	*-0.3* *(-3.6, 3.1)*
Median Forecast*	**-15.6**	*0.3*	**0.0**	*1.1*	**0.3**	*1.5*

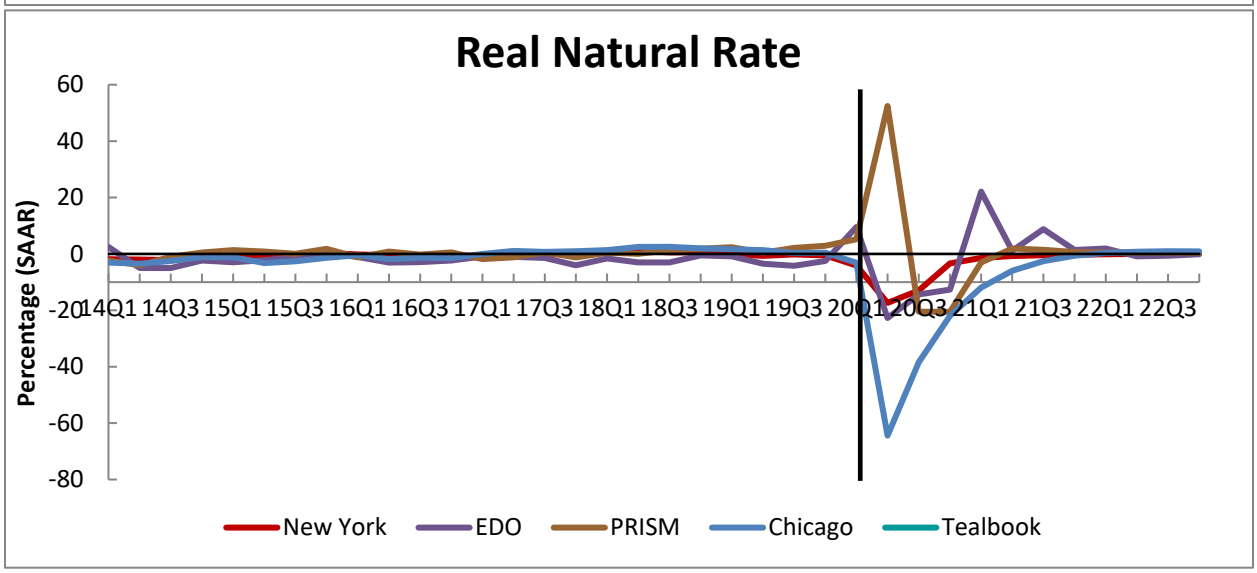
Model	Output Gap (Q4)					
	2020		2021		2022	
	June	*March*	**June**	*March*	**June**	*March*
EDO - Board of Governors	**-2.3 (-10.4, 2.1)**	*0.0 (-1.0, 1.0)*	**5.7 (2.6, 8.6)**	*-0.3 (-2.0, 1.4)*	**3.4 (0.2, 6.6)**	*-0.4 (-2.4, 1.6)*
New York Fed	**-5.7 (-9.3, -3.3)**	*-0.3 (-2.2, 1.5)*	**-4.8 (-9.9, -2.2)**	*-0.4 (-3.0, 2.2)*	**-4.9 (-10.4, -2.0)**	*-0.4 (-3.5, 2.8)*
PRISM - Philadelphia Fed	**-2.1 (-4.0, -0.3)**	*0.2 (-0.3, 0.6)*	**-1.8 (-3.2, -0.4)**	*0.1 (-0.7, 0.9)*	**-1.4 (-2.8, -0.1)**	*0.1 (-0.9, 1.2)*
Chicago Fed	**-6.3 (-7.1, -5.5)**	*2.6 (1.8, 3.4)*	**-3.1 (-5.1, -1.0)**	*2.3 (0.2, 4.4)*	**-2.5 (-5.2, 0.3)**	*1.3 (-1.5, 4.1)*
Median Forecast*	**-4.0**	*0.1*	**-2.4**	*-0.1*	**-2.0**	*-0.2*
June Tealbook	**-5.0**		**-1.0**		**0.7**	

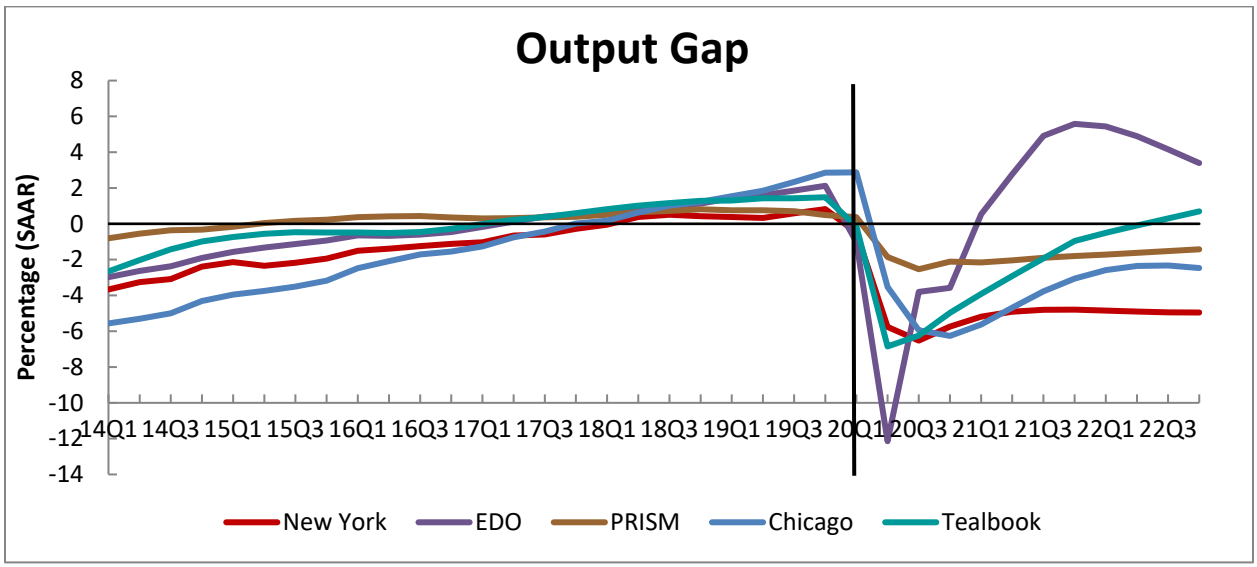
For each individual forecast, the numbers in parentheses represent 68% confidence bands.
*The median forecast is calculated as the median of the Q4/Q4 projections from the forecasters.


Real GDP Growth
Percentage (SAAR)
50
40
30
20
10
0
-10
-20
-30
-40
-50
14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3 20Q1 20Q3 21Q1 21Q3 22Q1 22Q3
New York
EDO
PRISM
Chicago
Tealbook


Core PCE Inflation
Percentage (SAAR)
3
2
1
0
-1
-2
-3
-4
-5
14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3 20Q1 20Q3 21Q1 21Q3 22Q1 22Q3
New York
EDO
PRISM
Chicago
Tealbook


Federal Funds Rate
Percentage
3
2.5
2
1.5
1
0.5
0
New York
EDO
PRISM
Chicago
Tealbook
14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3 20Q1 20Q3 21Q1 21Q3 22Q1 22Q3


Real Natural Rate
Percentage (SAAR)
60
40
20
0
-20
-40
-60
-80
14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3 20Q1 20Q3 21Q1 21Q3 22Q1 22Q3
New York
EDO
PRISM
Chicago
Tealbook


Output Gap
Percentage (SAAR)
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
14Q1 14Q3 15Q1 15Q3 16Q1 16Q3 17Q1 17Q3 18Q1 18Q3 19Q1 19Q3 20Q1 20Q3 21Q1 21Q3 22Q1 22Q3
New York
EDO
PRISM
Chicago
Tealbook

Detailed Descriptions of Individual Model Forecasts

The EDO Model

The EDO model forecast is informed by the drastic deterioration in economic activity in the current quarter implied by the staff's nowcast as well as by the staff's assessment of the likely effects of social distancing over the next several quarters. The model forecasts GDP to fall by 3.3 percent this year, and then to rebound by 8.4 percent in 2021; growth in 2022 is near zero.[3] Inflation is subdued, reaching 1.6 percent by 2022. The federal funds rate remains at the effective lower bound (ELB) until mid-2022, reflecting both an accommodative monetary policy stance and the sluggish pace of economic activity following the rebound.

Because the disruption associated with the pandemic in 2020Q2 lies far outside the model's estimation sample and structure, we guide the model using the staff's assumptions for social distancing effects on consumption, investment and employment through the end of 2021. In the model, we represent this sequence of effects using shocks to technology and household preferences for consumption and investment that are anticipated by private agents in 2020Q2.

With the federal funds rate at the effective lower bound in 2020Q2, we also assume that the public in that quarter expects the federal funds rate to remain at the ELB until the middle of 2022, in line with survey evidence suggesting expectations of an ELB episode of several years. The social distancing effects alone would not justify remaining at the ELB for such an extended duration. The expectation of an eight quarter spell at the ELB arises instead from the arrival of news about the future stance of monetary policy, which the model views as unusually accommodative. When calculating the distribution of outcomes over the forecast horizon, we assume that monetary policy keeps the federal funds rate at the ELB until mid-2022 without reference to particular exit conditions.

Uncertainty about the path of the pandemic and its attendant macroeconomic effects is a central element of the model projection in these circumstances. In particular, motivated by the substantial probability that secondary epidemics may trigger renewed bouts of intense social distancing, we assume that a second wave may begin in any quarter between 2020Q3 and 2021Q1 with a 50 percent probability each quarter; the course of the second wave follows that of

[3] The Alternative Models exhibit in the Risks and Uncertainty section of the Tealbook reports an alternative forecast using the EDO model, but conditioning on the staff's forecast for 2020 as a whole.

the first, but with a scale uniformly distributed between 25 and 75 percent the size of the first wave. Consistent with this highly asymmetric distribution of risks stemming from the pandemic and the adverse skew arising from the binding ELB, the distribution for output growth in 2020 is markedly tilted towards the downside, with the lower edge of the 68 percent confidence interval reaching -9.5 percent, more than 6 percentage points below the median outcome.[4] The median outcome itself reflects the arrival of a relatively mild second wave. Nevertheless, despite the large fall in GDP in the second quarter, and the high probability of a second wave in the second half of the year, in most cases, output rapidly regains its previous peak and the output gap closes by the beginning of 2021.

In contrast to output, the distribution of risk for inflation is not especially wide or asymmetric, as most of the variation in inflation is driven by shocks to the Phillips curve unrelated to economic activity. Although inflation remains low at the end of 2022, the federal funds rate exits immediately as soon as the estimated rule assumes control and rises to 1.2 by the end of the year, with even the lower edge of the 68 percent confidence interval of the forecast distribution above the ELB at that time.

The NY Fed Model

The New York Fed model forecasts are obtained using data released through 2020Q1, augmented for 2020Q2 with the New York Fed staff forecasts (as of May 14) for real GDP growth and core PCE inflation, and the yields on 10-year Treasuries and Baa corporate bonds based on 2020Q2 averages up to May 14. Moreover, the forecast is conditional on federal funds rate expectations derived from OIS data through 2021Q4.

The model was changed in order to address the implications of the COVID-19 shock. Most of the exogenous processes in the model are estimated to be persistent, reflecting the persistence of macroeconomic time series. The COVID-19 shock is likely to be different from standard business cycle shocks, in that some of its effects on economic activity, such as the shutdown of businesses, are temporary. The model is therefore augmented with a number of both demand and supply shocks that are purely transitory and hit the economy in 2020Q1, Q2, and also potentially

[4] By comparison, in the previous System DSGE memo, the confidence intervals for GDP growth in 2020 were about 1¾ percentage points on either side of the median.

Q3. The demand shocks are so-called discount rate shocks that affect intertemporal consumption decisions, while the supply shocks are both productivity shocks and labor supply shifters. The standard deviations of these transitory shocks are drawn from a relatively uninformative prior distribution, allowing for uncertainty in the interpretation of the shutdown as a supply- or demand-driven phenomenon.

The degree to which the COVID-19 shock will have persistent effects on growth and inflation is very uncertain, both because little is known about the channels of transmission of the shock, and the likelihood of recurrence (i.e., future waves of contagion). This uncertainty is captured in the NY Fed DSGE forecasts using a combination of three scenarios, which are referred to as the "Temporary Shutdown", "Shutdown with Business Cycle Dynamics", and "Persistent Demand Shortfall" scenarios. The "Temporary Shutdown" scenario explains the decline in economic activity in 2020Q1 and Q2 using predominantly the transitory shocks mentioned above, and intentionally limiting the role of standard shocks in these two quarters. This yield a relatively V-shaped recovery, with Q4/Q4 GDP growth in the neighborhood of -4.5 percent. In the "Shutdown with Business Cycle Dynamics" we allow for the usual set of shocks that populate the model to play a larger role, yielding more persistent effects, with Q4/Q4 GDP growth in the neighborhood of -6.5 percent. Finally, in the "Persistent Demand Shortfall" scenario the temporary demand shortfall is assumed to persist through Q3, reflecting prolonged weakness in demand, and is anticipated in Q2. This scenario yields Q4/Q4 GDP growth in the neighborhood of -12 percent.

The three scenarios are combined using weights (60, 25, and 15 percent, respectively) that are loosely informed by the Philadelphia Fed Survey of Professional Forecasters (SPF) average probability distribution for 2020 year-over-year real GDP growth.

In the combined forecast real GDP growth is expected to be -6.2 percent in 2020 on a Q4/Q4 basis. In 2021 and 2022, GDP growth is projected to recover to 2.1 and 0.8 percent respectively, compared to the March projection of 1.8 and 1.9 percent growth in 2021 and 2022. Core inflation is projected to be 1.5 percent in 2020, in line with the March projection. However, inflation is expected to be weaker throughout the forecast horizon, at 1.1 percent in both 2021 and 2022, lower than the March projection of 1.4 percent. The small slope of the Phillips curve in the DSGE model implies that the contraction in activity has a relatively small, but prolonged, effect on inflation.

The projections are surrounded by an enormous degree of uncertainty. For instance, the 68 percent probability interval ranges from -9.4 to -4 percent for 2020 GDP growth, and from -1.5 to 4 percent for 2021 GDP growth. In comparison, the posterior probability intervals for inflation are much tighter.

While a priori the COVID-19 shock can be interpreted as a combination of both supply and demand shocks, the model mostly leans on the latter in order to explain the data. As a consequence, the real natural rate falls temporarily by a large amount, reflecting the transitory nature of the shocks, although it recovers relatively rapidly. The real natural rate is -3.3 percent in 2020, 4.1 percentage points lower than the March projection, and rises to -0.3 and 0.2 percent in 2021 and 2022, respectively. The output gap is estimated to be persistently negative, at about -5 percent, throughout the forecast horizon.

The Philadelphia Model

The Philadelphia model's forecast is constructed using data through 2020Q1 supplemented with a 2020Q2 current-quarter forecast based on the most recent IHS forecast and staff judgement. Given the unusual circumstances surrounding economic behavior in response to coronavirus pandemic, the modelers took several measures in order to bring the projections in line with their assessment regarding the evolution of the economy over the next few quarters. These measures include fixing the federal funds rate at the effective lower bound until 2023Q4; fixing the two-year Treasury rate at the ELB until 2021Q1 to bring it in line with our assumption on the federal funds rate; setting core inflation for 2020Q3 and 2020Q4 so that the inflation forecast for 2020 is in line with the median projection from our staff; fixing the unemployment rate in 2020Q4 at the median forecast of our staff; fixing the weighted average of government spending and next exports in 2020Q2 and 2023Q3 at the IHS baseline forecast to capture actual and anticipated government relief/stimulus.

The nowcast for 2020Q2 sets real GDP growth at -36 percent, the unemployment rate at 18.1 percent, core inflation at 0.3 percent, and the federal funds rate at 0.12 percent. Under this nowcast, the model generates an output gap of -1.9 percent and a natural rate of interest rising to almost 53 percent. Finally, forecast uncertainty is scaled up in line with forecasters' assessment of uncertainty from the latest SPF.

Looking ahead, real GDP is expected to grow at 6.5 percent in 2020Q3 and 22.5 percent in Q4. For 2020 as a whole, real GDP growth is projected to be -3.1 percent, rising to 2.2 percent in 2021 and 3.2 percent in 2022. Thus, the model does not anticipate an extended period of significantly above-trend growth to offset the economic damage from the pandemic. The inflation projection is much lower in this forecast compared to the March projection: core PCE inflation posts at 1.2 percent in 2020 and then runs at about a 0.6 percent pace over the following three years. As mentioned above, the federal funds rate is set at the ELB over the forecast horizon. The unemployment rate hits a high of 19 percent in 2020Q3 and then falls gradually to reach 6.7 percent in 2023Q4 – thus remaining well above estimates of the natural rate of unemployment over the next three and a half years.

After rising sharply in Q2, the natural rate of interest falls into negative territory over the second half of 2020 averaging about -20 percent before returning into positive territory in 2021Q2. At the end of the forecast horizon in 2023Q4, the natural rate of interest is 0.2 percent. The output gap stands at -1.9 percent in 2020Q2, falling to a low of -2.5 percent in Q3. Over the remainder of the forecast horizon, the output gap shrinks slowly – reaching -1 percent in 2023Q4.

According to the model, the negative output growth in the second quarter is driven by negative shocks to preferences (the discount factor), which leads to a to 35 percent decline in consumption in 2020Q2, and investment. Output growth rebounds over the next few quarters following a sharp rebound in investment together with positive contribution from government spending shocks. The effects of these shocks wane quickly though and by mid-2021 it is primarily preference shocks that are keeping output growth only slightly above its trend pace. Consumption growth remains negative in Q3, and turns positive in Q4.

Core inflation is expected to run at a pace well-below target pace over the forecast horizon. Factors pulling down inflation include the shocks to investment and the discount factor. While markup shocks impart an upward pull to inflation dynamics, they wear off quickly and are unable to fully offset the negative contributions from investment and preference shocks.

The Chicago Fed Model

The Chicago Fed DSGE model forecast is constructed using data through 2020Q1 supplemented by a number of assumptions based on market expectations, survey data, and judgments for the second quarter of 2020. The assumption for GDP growth for 2020Q2 is -30 percent at an annualized rate based on Macro Advisers and on the SPF. The forecast also incorporates judgmental assumptions for the main components of GDP growth, consumption and investment, assuming that their weighted sum generate a small residual spending. The federal fund rate is at the effective lower bound (ELB) and expected to stay at the ELB until the end of the forecasting horizon (i.e. 2022Q4), in line with the Survey of Market Participants. The conditioning assumptions also include 2020Q2 actual and expected inflation, both one-quarter ahead and over the next 10 years, taken from the first quarter SPF. The CPI inflation numbers for 2020Q2 are constructed by extending the monthly inflation rate from March to April to the months of May and June and computing the implied quarterly inflation rate; this results in -3.6 percent annualized inflation rate for core CPI and -3.9 for core PCE in 2020Q2. The forecast also reflects a projection for hours worked in Q2 based on the unemployment rate.

The model does not feature a specific COVID-19 shock. However, since the liquidity preference disturbance is a demand shock that invariably plays a key role in explaining recessions over the estimation sample, the modelers also assume that this type of disturbance is also the leading shock behind the current recession. More precisely, the shock causing the COVID-19 recession (in short, the COVID-19 shock) is assumed to be dormant throughout our full sample, i.e. from 1993Q1 to 2019Q4. In the first two quarters of 2020, this COVID-19 shock hits the US economy and from 2020Q3 reverts to being dormant again. This liquidity COVID-19 shock, however, has a different standard deviation and persistence than the estimated liquidity preference shock in the model, in order to reflect the peculiarities of the current situation. The standard deviation of the COVID-19 shock is chosen to maximize the likelihood function over the first two quarters of 2020, reflecting both the judgmental assumptions and the data for those quarters. The persistence of the COVID-19 recession is assumed to be moderate, so that most of the effects of the shock are concentrated in 2020. The other structural parameters are kept at their in-sample estimates except for the standard deviation of the estimated liquidity preference shock and the permanent neutral

technology shocks. These are both set to zero, thereby preventing these shocks from explaining the data in the first half of 2020. [5]

The deep trough in 2020Q2 is a combination of the COVID-19 shock and the investment specific technological change (ISTS); the estimated magnitude of both shocks is extremely large. While the COVID-19 shock is short-lasting, the economic slump in 2020Q2 is so severe that GDP growth is expected to resume only in the last quarter of the year; yielding a Q4/Q4 GDP growth of –12.4 percent. The economy rebounds in 2021 with a GDP growth forecast of 3.9 percent.

While monetary policy is constrained by the ELB in 2020, the expectation that the federal funds rate remain at the ELB until the end of the forecasting horizon more than offset the contractionary effects of the ELB, leading monetary policy to positively contribute to the model's forecasts for GDP growth. However, the removal of this large monetary accommodation acts as a severe drag for the real economy in 2022. As a result, the model forecasts GDP growth at 0.4 percent in 2022.

The forecast for Q4/Q4 core PCE inflation is substantially below target in 2020, at 0.3 percent. This number is mostly due to the judgmental assumptions for 2020Q2. The weakness in inflation comes from both measurement errors and the negative contribution of the COVID-19 and ISTS shocks. Measurement errors are short-lasting and inflation is forecasted to rise relatively quickly approaching the FOMC's long run goal from below. In particular, inflation averages 1.8 percent in 2021 and 1.6 percent in 2022.

Fluctuations in the natural rate are mostly explained by the COVID-19 shock. Since the magnitude of the COVID-19 shock is estimated to be very large by historical standards, the estimated drop of the natural rate 2020 is very pronounced. In particular, the model forecasts that the (real) natural rate of interest at the end of the year for 2020 through 2022 will equal -22, -0.6, and 0.9 percent respectively. The model forecasts end-of-year output gaps for 2020 through 2022, at -6.3, -3.1, and -2.5 percent respectively.

The uncertainty surrounding these forecasts is very large.

[5] The permanent neutral technology shock also plays an important role in accounting for recessions. In the forecasts presented here, we do not use this shock to model the economic effects of COVID-19 as this shock tends to have inflationary pressure that we consider as implausible.