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

Date: September 9, 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

September 4, 2020

Filippo Ferroni, Jonas D. Fisher and Leonardo Melosi[1]

Federal Reserve Bank of Chicago

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

As discussed in our previous round memo the COVID-19 induced recession is very difficult to rationalize with existing DSGE models and, in general, with the standard econometric time-series toolset, which implies that forecasting the effects of COVID-19 going forward is problematic. The challenges are multiple: the COVID-19 induced recession is extremely large; unobserved before 2020; and with a substantially unknown nature, i.e. whether supply- or demand-driven. Moreover, the propagation of the COVID-19 disruption is very fast and most likely very different from the typical transmission of business cycles shocks.

While each model coped with these difficulties by adopting a specific approach, all of them relied either on the use of external information or on the use of *novel* shocks, or both. The use of external information was primarily meant to offer more guidance and discipline to the models, which were substantially unequipped to describe the dynamics of the COVID-19 related disruptions, e.g. social distancing measures. In this respect, the New York and Chicago Fed's use Survey of Professional Forecasters expectations about the near term GDP and inflation projections. The EDO model (Board) makes use of staff projections for social distancing effects on consumption, investment and employment through the end of 2021. 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.

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

economy. Moreover, some of these novel shocks embed news about their future propagation, e.g., the Chicago and New York Fed's.

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. In particular, some point forecasts are the result of the combination of a baseline or central scenario with alternative simulations. For example, the Board, the Chicago Fed and the New York Fed consider an alternative scenario where a second wave of virus resurgence is probable in the coming fall and/or winter; albeit the size of the disruption is assumed to be smaller than the one observed during the first wave.

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 September Tealbook forecasts, as well as the DSGE model forecasts prepared for the June 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.

Q4/Q4 GDP growth forecasts for the current year range from a pessimistic -4.1 percent (New York) to a relatively optimistic -2.3 percent (Chicago). The median of the point forecasts across models is -3.5 percent. Relative to last round the forecast has been revised upward by 1.3 percent, partially reflecting the expected rebound in economic activity in 2020Q3 embedded in most of the conditioning assumptions. Moreover, the dispersion across point forecasts[2] has reduced considerably relative to last round as well as the individual uncertainty. This is also due to the fact that most of 2020 is data. More interesting is the forecast for next year. All the models predict a

---

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

rebound of GDP in 2021; the extent of this rebound varies across models with New York being more optimistic (5.9 percent) and Philadelphia more subdued (2.7 percent). The median value across models is at 4.7 percent. Uncertainty is very large as the 68 percent coverage intervals include negative growth for two out of four models. For all the models but PRISM, growth in 2022 decelerates generating a median GDP growth of 3.2. In 2023, two models out of four see GDP growth below potential and two above. Again, uncertainty remains large as the 68 percent coverage intervals include negative growth for two out of four models.

In terms of inflation forecasts, all models agree that inflation will be well below the FOMC's long run goal; these projections are revised slightly downwards relative to the June projections. Core PCE inflation forecasts for 2020 range from 0.6 to 1.5 percent. Inflation remains subdued throughout the forecast horizon with a median point forecast for 2020 through 2023 of 0.8 percent, 1.0 percent and 1.2 percent respectively. In spite of the massive decline in economic activity, two out of four models do not see chances of deflation as the coverage bands do not include negative values. This is largely because all DSGEs feature a rather flat Phillips curve.

Forecasts for the federal funds rate[3] are not particularly informative as all models condition on either market or survey expectations at least until the beginning of 2022. EDO and the NY Fed models see the federal funds rate rising to about 1 percent by the end of 2022. Chicago sees the federal funds rate rising in 2023 and PRISM pegs the federal funds rate at the ELB through the end of 2023.

The DSGE models' interpretation of the COVID-19 shock—as either mainly a demand or a supply shock—can be inferred from the estimated behavior of the natural rate of interest. For all models the natural rate of interest falls (in same cases quite dramatically) in the second quarter of 2020 when social distancing and COVID-19 containment measures were in place. Its dynamic propagation is however quite different across models. At the end of year, the point estimates stretch from -16.7 percent (Chicago Fed) to 7.8 percent (EDO). Towards the end of the forecast horizon, the natural rate of interest turns positive for three out of four models.

---

[3] All models but one consider the federal funds rate as the average value over the quarter. The Chicago Fed model is the exception, where the end of the quarter values is considered. This allows a smoother transition between the current federal funds rate and its future expected path which is an input to the model.

Finally, all models see a widening of the output gap in the current year, with actual output being from 5.6 to 1 percent below natural output by the end of 2020. For all but one model the gap remains negative throughout the forecast horizon. EDO is the exception, in that its gap rises to 2.3 percent in 2021 and remains positive afterwards.

Forecasts

Model	Output Growth (Q4/Q4)						
	2020		2021		2022		2023
	September	June	September	June	September	June	September
EDO - Board of Governors	-2.9 (-3.8, -1.9)	-3.3 (-9.5, -0.2)	5.4 (2.8, 8.1)	8.4 (3.1, 14.2)	3.1 (0.7, 5.6)	0.4 (-1.9, 2.7)	1.1 (-1.1, 3.2)
New York Fed	-4.1 (-5.7, -3)	-6.2 (-9.4, -4.0)	5.9 (1.9, 8.1)	2.1 (-1.5, 4.2)	4.4 (1.2, 7.1)	0.8 (-2.1, 3.4)	3.9 (1.2, 7.0)
PRISM - Philadelphia Fed	-4.1 (-6.6, -1.6)	-3.1 (-7.7, -1.6)	2.7 (-3.5, 9)	2.2 (1.8, 6.2)	3.4 (-4.3, 11)	3.0 (-0.0, 6.1)	3.3 (0.8, 5.7)
Chicago Fed	-2.3 (-4.8, -0.2)	-12.4 (-14.4, -10.4)	4.1 (-1.3, 9.4)	3.9 (-0.7, 8.4)	1.5 (-3.7, 6.6)	0.4 (-4.3, 5.1)	1.4 (-4.0, 6.9)
Median Forecast*	-3.5	-4.8	4.7	3.0	3.2	0.6	2.3
September Tealbook	-3.2		4.2		3.2		2.8

Model	Core PCE Inflation (Q4/Q4)						
	2020		2021		2022		2023
	September	June	September	June	September	June	September
EDO - Board of Governors	1.5 (1.4, 1.6)	0.1 (-0.2, 0.5)	1.4 (0.7, 2.1)	1.0 (0.14, 1.9)	1.3 (0.3, 2.3)	1.6 (0.6, 2.7)	1.5 (0.5, 2.6)
New York Fed	0.8 (0.6, 1.0)	1.5 (1.1, 1.9)	0.7 (-0.2, 1.6)	1.1 (0.1, 2.0)	1.0 (-0.1, 2.1)	1.1 (-0.0, 2.2)	1.3 (0.1, 2.6)
PRISM - Philadelphia Fed	0.6 (0.1, 1.1)	1.2 (1.2, 1.2)	0.3 (-1.8, 2.4)	0.6 (-0.2, 1.4)	0.9 (-0.2, 2.1)	0.5 (-0.4, 1.4)	1.5 (-0.2, 3.1)
Chicago Fed	0.8 (0.5, 1.1)	0.3 (-0.3, 0.9)	1.8 (0.5, 3)	1.8 (0.6, 3.0)	1.5 (0.3, 2.8)	1.6 (0.4, 2.9)	1.5 (0.3, 2.7)
Median Forecast*	0.8	0.8	1.0	1.1	1.2	1.4	1.5
September Tealbook	1.3		1.7		1.8		1.9

Model	Federal Funds Rate (Q4)						
	2020		**2021**		**2022**		**2023**
	September	*June*	**September**	*June*	**September**	*June*	**September**
EDO - Board of Governors	**0.1** (0.1, 0.1)	0.1 (0.1, 0.1)	**0.1** (0.1, 0.1)	0.1 (0.1, 0.1)	**0.9** (0.1, 1.6)	1.2 (0.2, 2.4)	**2.2** (0.6, 3.8)
New York Fed	**0.1** (0.1, 0.8)	0.0 (0.0, 1.2)	**0.0** (0.1, 1.7)	0.1 (0.0, 1.8)	**1.1** (0.2, 3)	1.1 (0.1, 3.1)	**2.0** (0.6, 4.1)
PRISM - Philadelphia Fed	**0.1** (0.1, 0.1)	0.1 (0.1, 0.1)	**0.1** (0.1, 0.1)	0.1 (0.1, 0.1)	**0.1** (0.1, 0.1)	0.1 (0.1, 0.1)	**0.1** (0.1, 0.1)
Chicago Fed	**0.1** (0.1, 0.2)	0.1 (-0.2, 0.4)	**0.1** (0.1, 0.2)	0.1 (-1.1, 1.4)	**0.1** (0.1, 0.1)	0.1 (-1.9, 2.1)	**1.1** (-0.7, 3.1)
Median Forecast*	**0.1**	0.1	**0.1**	0.1	**0.5**	0.6	**1.6**
September Tealbook	**0.1**		**0.1**		**0.1**		**0.1**

Model	Real Natural Rate of Interest r* (Q4)						
	2020		**2021**		**2022**		**2023**
	September	*June*	**September**	*June*	**September**	*June*	**September**
EDO - Board of Governors	**7.8** (2.3, 13.4)	-10.8 (-34.4, 7.8)	**0.1** (-10.1, 9.9)	0.2 (-6.4, 10.0)	**-2.4** (-7.6, 2.7)	-0.1 (-5.1, 4.8)	**1.1** (-3.8, 6)
New York Fed	**-3.7** (-6.7, -0.7)	-3.3 (-4.9, -1.8)	**-1.5** (-3, 0)	-0.3 (-1.8, 1.3)	**-0.5** (-2.1, 1.2)	0.2 (-1.4, 1.9)	**0.2** (-1.5, 1.9)
PRISM - Philadelphia Fed	**-4.8** (-11.0, 1.5)	-20.5 (-35.2, -5.7)	**-0.5** (-10, 8.9)	0.7 (-7.3, 8.6)	**0.7** (-7.9, 9.3)	0.4 (-5.5, 6.2)	**1.5** (-4.8, 7.8)
Chicago Fed	**-16.7** (-50.6, -2.1)	-22.0 (-24.2, -19.7)	**-1.2** (-8.3, 5.9)	-0.6 (-3.7, 2.4)	**-1.2** (-8.5, 6.1)	0.9 (-2.4, 4.2)	**-0.5** (-7.6, 6.7)
Median Forecast*	**-4.2**	-15.6	**-0.9**	0.0	**-0.8**	0.3	**0.6**

Model	Output Gap (Q4)						
	2020		2021		2022		2023
	September	*June*	September	*June*	September	*June*	September
EDO - Board of Governors	**-2.2**	-2.3	**2.3**	5.7	**2.1**	3.4	**0.9**
	(-3.1, -1.4)	(-10.4, 2.1)	**(-0.2, 4.7)**	(2.6, 8.6)	**(-1.0, 5.1)**	(0.2, 6.6)	**(-2.0, 3.7)**
New York Fed	**-5.6**	-5.7	**-3.4**	-4.8	**-2.3**	-4.9	**-1.4**
	(-7.5, -4.1)	(-9.3, -3.3)	**(-7.2, -1.7)**	(-9.9, -2.2)	**(-7.2, 0.0)**	(-10.4, -2.0)	**(-6.4, 1.6)**
PRISM - Philadelphia Fed	**-1.0**	-2.1	**-1.1**	-1.8	**-0.7**	-1.4	**-0.3**
	(-1.8, -0.2)	(-4.0, -0.3)	**(-2.0, -0.2)**	(-3.2, -0.4)	**(-1.9, 0.5)**	(-2.8, -0.1)	**(-2.0, 1.3)**
Chicago Fed	**-2.5**	-6.3	**-1.2**	-3.1	**-1.4**	-2.5	**-1.6**
	(-3.6, -1.5)	(-7.1, -5.5)	**(-4.1, 1.7)**	(-5.2, -1.0)	**(-4.6, 1.7)**	(-5.2, 0.3)	**(-4.5, 1.2)**
Median Forecast*	**-2.4**	-4.0	**-1.2**	-2.4	**-1.1**	-2.0	**-0.8**
September Tealbook	**-1.3**		**0.3**		**1.5**		2.3

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

Core PCE Inflation

Federal Funds Rate

Real Natural Rate

Output Gap
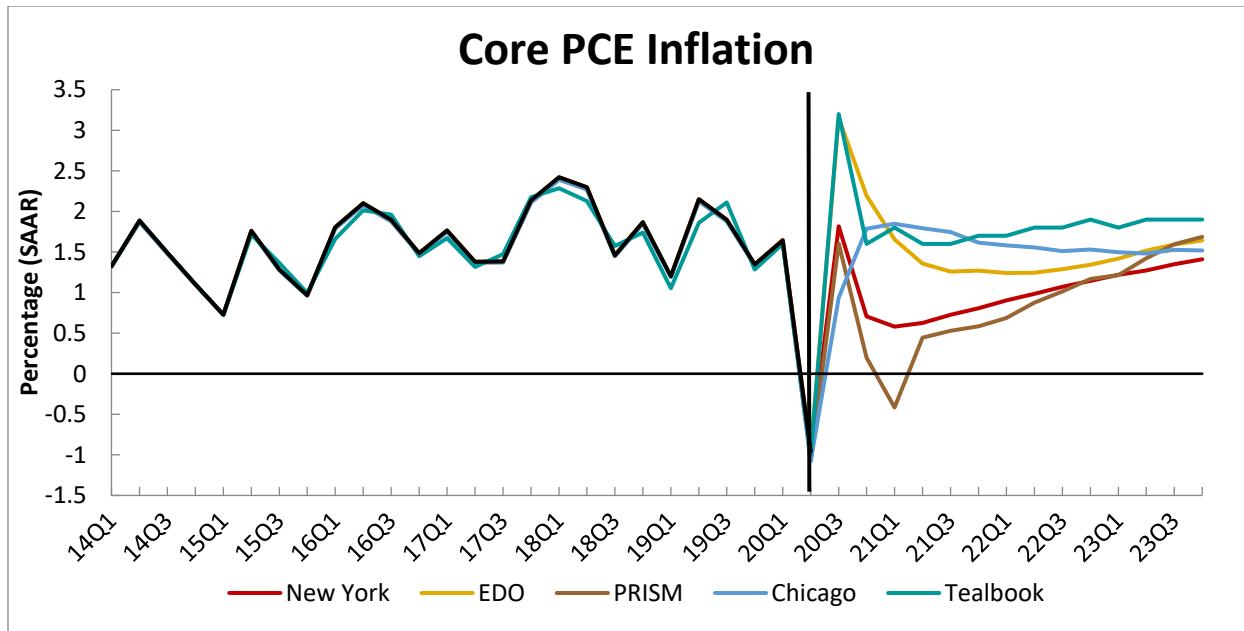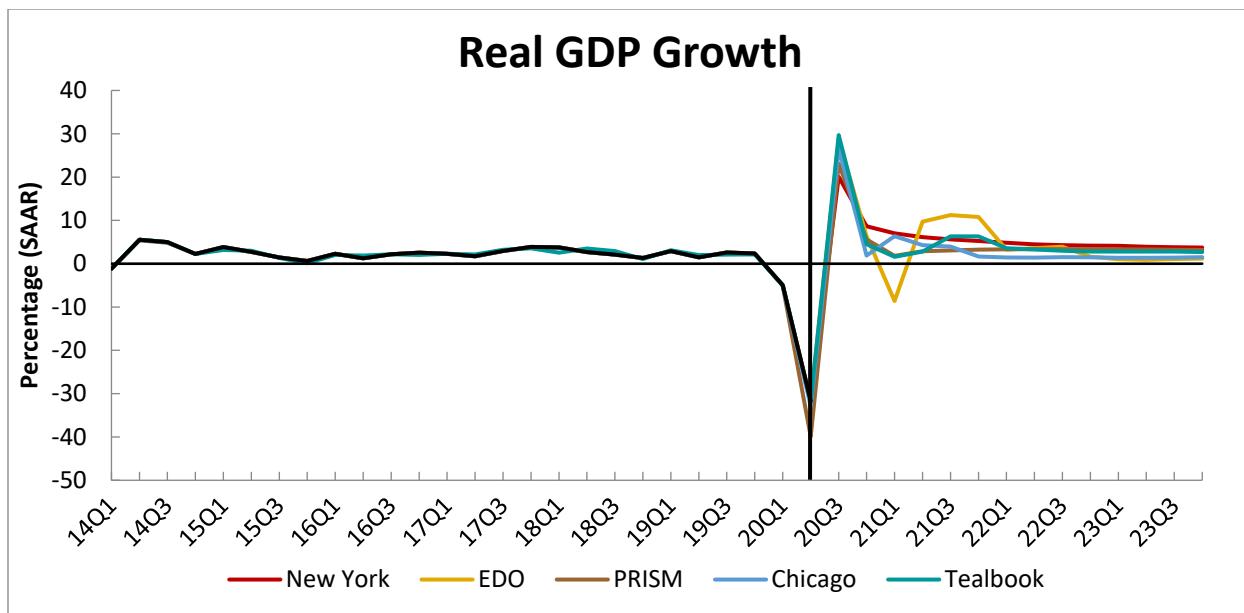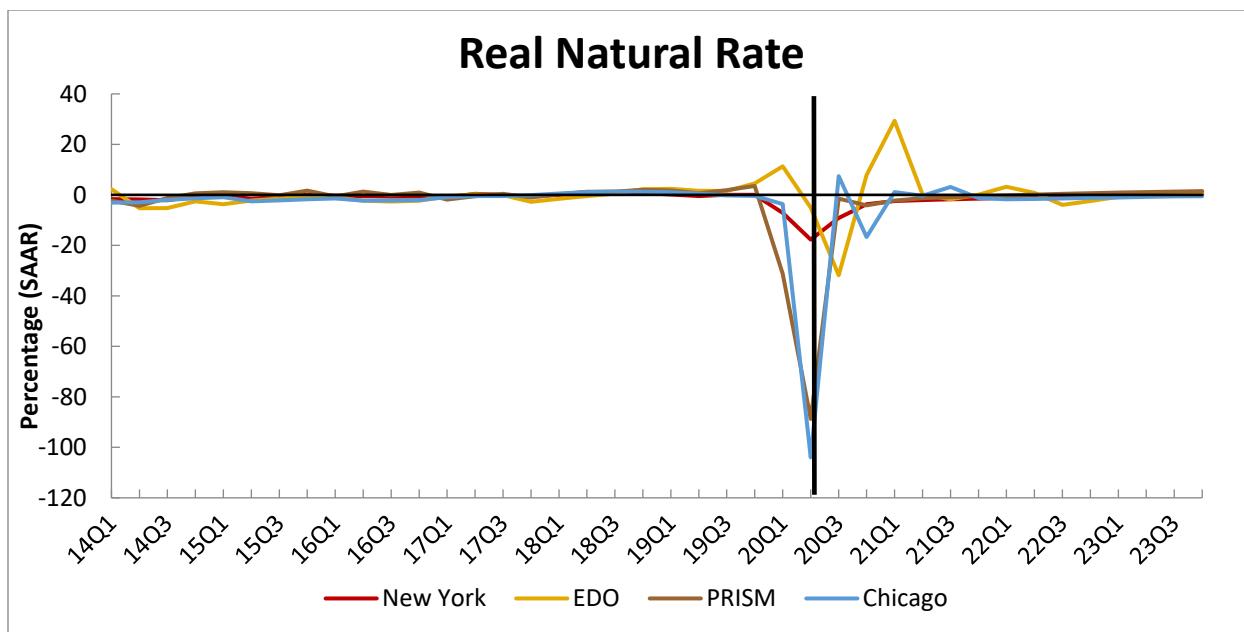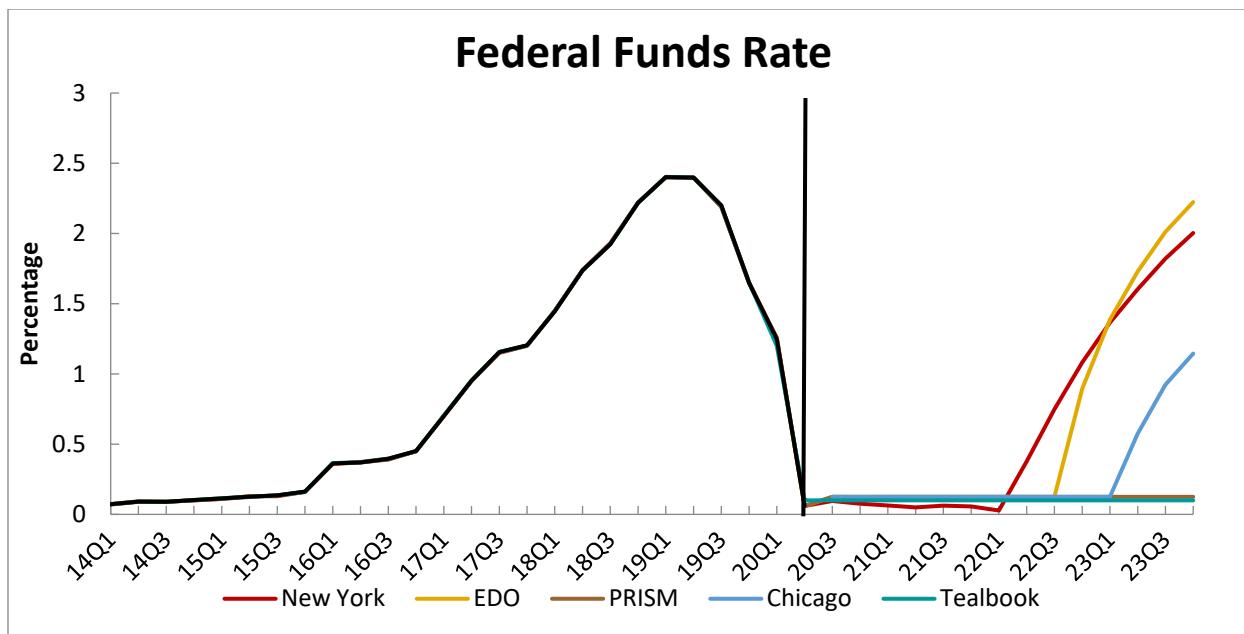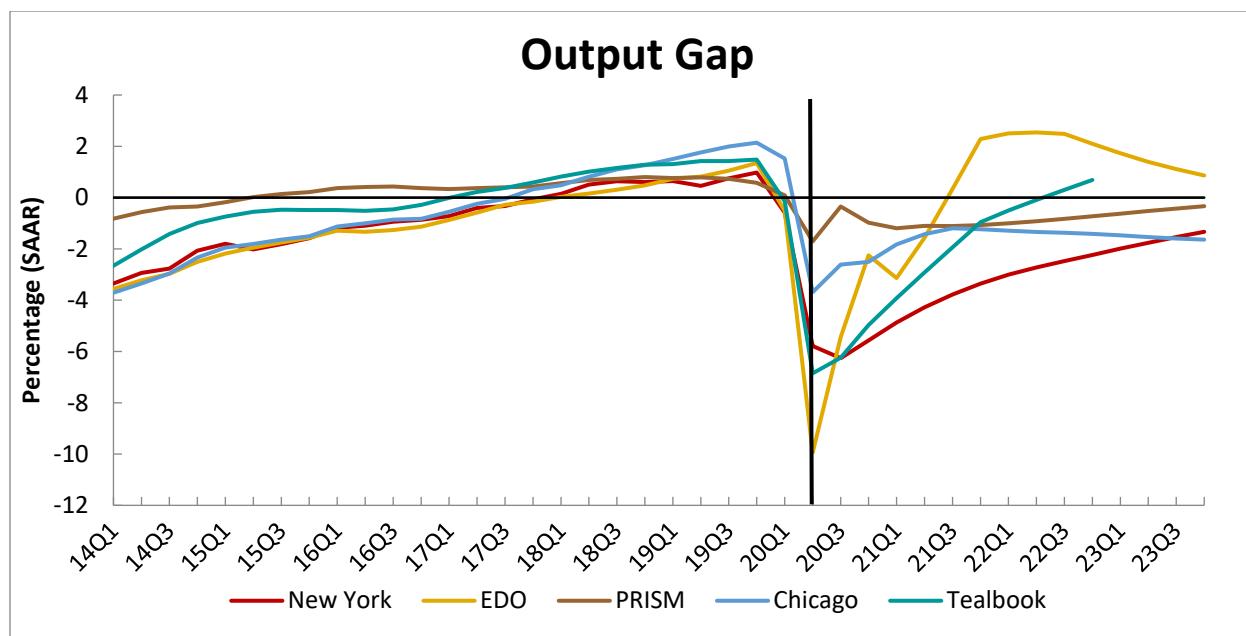
Detailed Descriptions of Individual Model Forecasts

<u>The EDO Model</u>

Reflecting the huge movements in economic activity in the data for 2020:Q2 and the staff's nowcast for 2020:Q3 –and informed by the staff's assessment of the likely effects of social distancing over the next several quarters– , the EDO model forecast calls for GDP to fall by 2.9 percent this year, and then to rebound 5.4 percent in 2021. Inflation is subdued, hovering around 1.5 percent through the end of 2023. The federal funds rate remains at the effective lower bound (ELB) until the end of 2022, reflecting both an accommodative monetary policy stance and the sluggish pace of economic activity following the rebound.

The EDO model forecast conditions on the data and nowcast for 2020:Q2 and 2020:Q3 and must therefore attempt to extrapolate from the unprecedented turmoil in those quarters. Because the disruption associated with the pandemic lies far outside the model's estimation sample and structure, we guide the model using the staff's projection for social distancing effects on consumption, investment and employment through the end of 2021.[4] In particular, in the model, we represent this sequence of effects by anticipated shocks to technology and household preferences for consumption and investment, recognized by private agents in 2020:Q2.

With the federal funds rate at the effective lower bound in 2020:Q2, 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 some survey evidence suggesting expectations of an ELB episode of several years. Given our calibration of social-distancing effects, these factors alone would not justify remaining at the ELB for an extended duration and the expectation of an extended 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.

As in June, uncertainty about the path of the pandemic and its attendant macroeconomic effects continues to be high. Motivated by the substantial probability that secondary epidemics may

---

[4] These assumptions regarding the course of social distancing effects were current as of the July Tealbook.

trigger renewed bouts of intense social distancing, we assume that a second wave may begin in 2020:Q4 and 2021:Q1 with a 25 percent probability each quarter; the course of the second wave follows that of the first, but between 25 and 75 as large, with a uniformly distributed scale. This assumption implies that the distribution of outcomes in those quarters exhibits a strong adverse bias relative to the modal forecast, as well an adverse skew in the tails of the distribution. The distribution near the center does not appear unusually broad or skewed. These stochastic simulations are performed under the assumption that monetary policy keeps the federal funds rate at the ELB until mid-2022 without reference to particular exit conditions. 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 0.9 percent by the end of the year; even the lower edge of the 95th percentile of the distribution is above the ELB at that time.

The NY Fed Model

The New York Fed model forecasts are obtained using data released through 2020Q2, augmented for 2020Q3 with the August Philadelphia Fed Survey of Professional Forecasters (SPF) median forecasts for real GDP growth and core PCE inflation (adjusted for the difference between the Blue Chip and SPF GDP deflator inflation forecasts, since the former incorporates the information in the August CPI release), the August consensus Financial Blue Chip forecasts for the GDP deflator, and the yields on 10-year Treasuries and Baa corporate bonds based on 2020Q3 averages up to August 27. Moreover, the forecast is conditional on federal funds rate expectations derived from OIS data through 2021Q4.

As mentioned in the June memo, the model was changed in order to address the implications of the COVID-19 shock. In particular, the model was augmented with a number of both demand and supply shocks that are purely transitory and hit the economy in 2020Q1, Q2, and Q3, in order to capture the partly temporary nature of the COVID-19 shock. 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, because little is known about either the channels of transmission of the shock, or 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 "Second Wave" 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 yields a relatively rapid recovery, with 2020 Q4/Q4 GDP growth of -3.8 percent and further rebound in economic activity in 2021 and 2022. In the "Shutdown with Business Cycle Dynamics" the usual set of shocks that populate the model (which have much more persistent dynamics than the COVID-19 shocks) play a larger role. This yields more persistent effects, with 2020 Q4/Q4 GDP growth in the neighborhood of -5 percent. It is worth noting that the forecast differences between these two scenarios are less stark than they were in June, at least for 2020, mostly because the second scenario projects higher output growth than it did back then. This indicates that the data so far point toward a robust recovery. In the medium run however, the two scenarios remain markedly different, with the second scenario predicting much more modest growth in 2021 and 2022.

Finally, the "Second Wave" scenario assumes a renewed weakness in demand in 2020Q4, reflecting a resurgence of the pandemic in that quarter. We implement this scenario by imposing that the current quarter expectation for real GDP growth in Q4 coincides with the 10th percentile of the cross-sectional distribution of SPF point forecasts (-0.36 percent, annualized). This scenario yields 2020 Q4/Q4 GDP growth in the neighborhood of -5.5 percent, not very distant from that in the second scenario. Differently from the second scenario, the "Second Wave" scenario features a stronger rebound of the economy in 2021 and 2022, as the effects of the second wave shock are transitory. Note that the "Second Wave" scenario replaces the "Persistent Demand Shortfall" scenario featured in the June forecast, which turned out to be counterfactual (at least assuming the median SPF projections are broadly correct) in that this demand shortfall did not quite materialize in the current quarter. In all three scenarios the model allows for both the COVID-19 and the standard business cycle shocks to be active in Q3, although both sets of shocks play a relatively small role in this quarter as the model's projections were largely in line with the SPF forecasts.

The three scenarios are combined using weights (80, 10, and 10 percent, respectively) that are loosely informed by the SPF average probability distribution for 2020 year-over-year real GDP growth.

In the combined forecast real GDP growth is expected to be -4.1 percent in 2020 on a Q4/Q4 basis, compared with a -6.2 percent projection in June. In 2021 and 2022, GDP growth is projected to recover to 5.9 and 4.4 percent respectively, much faster than predicted in June (2.1 and 0.8 percent, respectively). Core inflation is projected to be 0.8 percent in 2020, below the June forecast of 1.5 percent, and is expected to remain subdued throughout the forecast horizon, at 0.7 and 1.0 percent in 2021 and 2022, respectively. The small slope of the Phillips curve in the DSGE model implies that the drop in activity has a modest (relative to the size of the contraction) but prolonged effect on inflation.

The projections for all variables are surrounded by a large degree of uncertainty (although this has fallen somewhat relative to the June forecast for growth in 2020). For instance, the 68 percent probability interval ranges from -5.7 to -3 percent for 2020 GDP growth, and from 1.9 to 8.1 percent for 2021 GDP growth.

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 -3.7 percent in 2020, and rises to -1.5 and -0.5 percent in 2021 and 2022, respectively. The output gap is estimated to be persistently negative, rising gradually from -5.6 percent in 2020Q4 to -1.4 percent in 2023Q4.

The Philadelphia Model

The Philadelphia forecast is constructed using data through 2020Q2 that are then supplemented with a 2020Q3 current-quarter forecast based on the most recent IHS forecast and staff judgement. Given the unusual economic patterns in response to coronavirus pandemic, we have continued to adjust the model to better reflect our thinking about how the economy is likely to evolve over the forecast horizon. While our assumptions about fiscal and monetary policy have changed little, we have introduced additional shocks to demand and to the functioning of the labor market to induce responses that are consistent with the staffs' view on the forces driving the economy's dynamics

over the past few months. In this view, aggregate demand dropped as consumers experienced a short-lived increase in patience and found it harder to transform final goods to capital. In addition, perceived costs of vacancy creation and a drop in matching efficiency prevented hiring to offset job losses.

The nowcast for 2020Q3 sets real GDP growth at 23.1 percent at an annual rate, corresponding to a nowcast of actual growth of 26.0 percent, the unemployment rate at 9.5 percent, core inflation at 1.6 percent, and the federal funds rate at 0.12 percent. Under this nowcast, the model generates an output gap of -0.4 percent and an rstar of -1.5 percent. The level of rstar implies a big increased from the first half of 2020, when it was as low as -88.8 percent. The current output gap estimate improved compared to 2020Q2, when the model estimated it at -1.7 percent.

Looking ahead, real GDP is expected to grow at an annual rate of 5.6 percent in 2020Q4. For 2020 as a whole, real GDP growth is projected to be -4.1 percent. Over the next three years, real GDP grows, but remains above trend. In 2021, the model projects growth of 2.7 percent, followed by 3.4 percent in 2022 and 3.3 percent in 2023. Under this projection, the economy reaches its pre-pandemic level of real GDP in the first half of 2022. The model continues to project low inflation: Core PCE inflation is projected to average 0.6 percent in 2020, 0.3 percent in 2021, and 0.9 and 1.5 percent in 2022 and 2023, respectively. The FFR is fixed at the ELB throughout the forecast horizon. The unemployment rate declines gradually from 9.5 percent in the current quarter to 8.1 percent by the end of 2020, and falls to 5.2 percent by the end of 2023, almost one percentage above the natural rate of unemployment.

The natural rate of interest drops sharply in the first half of 2020 in response to the combination of short-lived Covid shocks. As these shocks dissipate, rstar jumps from -88.4 percent at an annual rate to -1.5 percent in 2020Q3, before falling to -4.1 percent in 2020Q4, in response to fading mark-up shocks, investment-specific shocks, and the dissipating Covid shocks. These shocks also keep the natural rate below zero in 2021. At the end of the forecast horizon in 2023Q4, the natural rate of interest is at 1.5 percent. 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 -0.3 percent in 2020Q3. In 2020Q4, the output gap is expected to drop to -1.0 percent. The output gap lies slightly below -1.0 percent in 2021. In 2022 and 2023, the output gap gradually narrows and reaches -0.3 percent in 2023Q4.

According to the Philadelphia model, the rebound in output growth in 2020Q3 is driven by the rebound from the effect of Covid-related shocks in the previous quarter. This effect carries over into 2020Q4, albeit to a lesser degree. The above-average output growth over the remainder of the forecast horizon is attributed to various shocks, most notably smaller effects of prior Covid-related shocks, investment specific technological progress, and monetary policy. Consumption dynamics closely follow that of output, and are driven by the same factors. The model attributes only half of the drop in investment in 2020Q2 to the short-lived Covid shocks, but these shocks explain most of the fall in investment in 2020Q1 and account for more than the estimated increase in investment growth in 2020Q3. The remaining drop in investment, as well as the subsequent rebound and above-average growth, is largely attributed to a persistent drop in investment-specific technology. The undoing of negative contributions from markup shocks and accommodative monetary policy also contribute noticeably to the above-trend investment growth from 2021 to 2023.

Core inflation is expected to run at a pace well-below target pace over the forecast horizon, and runs near zero in the near term. Covid-related shocks, although short-lived, pull inflation down by an average of -0.7 percentage point in 2021 and -0.2 percentage point in 2023. Apart from Covid-related shocks, the undoing of positive markup shocks and temporarily low TFP growth partly account for the weakening inflation in the near term. In addition, monetary policy, constrained by the ELB, is keeping inflation down, as is investment-specific technology.

The forecast is implemented with the federal funds rate pegged at the ELB through the end of 2023. Under this path for the federal funds rate, negative contributions from Covid-related shocks, investment shocks, and government consumption and investment are offset by positive contributions from markup and monetary policy shocks.

The Chicago Fed Model

The Chicago Fed DSGE model forecast is constructed using data through 2020Q2 supplemented by a number of assumptions based on market expectations, survey data and judgments for the third quarter of 2020. The assumption for GDP growth for 2020Q3 is 26.6 percent at an annualized rate based on Macro Advisers (MA). The forecast also incorporates assumptions for the main components of GDP growth, consumption and investment, based on MA forecasts and internal calculations. The federal fund rate is at the effective lower bound (ELB) and expected to stay there

until the first semester of 2023, in line with the Survey of Market Participants. The conditioning assumptions also include 2020Q3 expected inflation, both one-quarter ahead and over the next 10 years, taken from the first quarter Survey of Professional Forecasters (SPF). Unlike previous forecast rounds, our information set has been augmented with the SPF expectations about GDP growth and inflation for the next four quarter; these expectations are crucial to identify parameters that govern the propagation of the pandemic as we discuss next.

The Chicago Fed model does not explicitly feature a pandemic outbreak and its propagation. We model COVID-19 as a *synthetic* disturbance whose realizations could (i) affect contemporaneously different margins and wedges of the economy (i.e. supply, demand or intertemporal decisions…) and (ii) embed news about its near term propagations. The COVID-19 shock has thus a hybrid nature and a different transmission from usual structural business cycles shocks. The identification of the parameters seizing its size and persistence is achieved through the use of expectations and narrative restrictions; i.e. by assuming that the COVID-19 shocks explains most of the variation in 2020Q2 both in the actual and expected macroeconomic aggregates. More precisely, the shock causing the COVID-19 recession is assumed to be dormant throughout our full sample, i.e. from 1993Q1 to 2020Q1. In the second quarter of 2020, the COVID-19 shock hits the US economy while the relative importance of usual business cycles shocks is muted (this is achieved by reducing considerably the standard deviation of the structural business cycles shocks); its effects going forward unfold based on the SPF expectations about the likely course of the economy. Finally, we assume that this shock has a liquidity preference (demand) and a permanent neutral technology (supply) component and has an anticipation horizon of up to four quarters.

The defining features of this synthetic COVID-19 shock and its anticipation structure are pinned down by recent data, including the SPF one-, two-, three-, and four-quarters-ahead forecasts of GDP growth and inflation. The standard deviation of the COVID-19 shock, its anticipation structure, are chosen in quarters 2020Q2 and 2020Q3 so as to maximize the likelihood function in each of these quarters. The relative loadings on demand and supply shocks, which define the COVID-19 shock, are analogously estimated, but for these parameters only 2020Q2 data are used. As the model's projections were largely informed by the SPF forecasts, which were only marginally revised in 2020Q3, the COVID-19 shock turns out to play a relatively small role in this quarter.

Motivated by the positive probability of the virus resurgence in the fall of this year, the point forecasts presented in this memo are constructed combining two scenarios: a neutral tendency where no more COVID-19 shocks are expected in the future ("baseline scenario") and a more pessimistic view where a second wave (half of the size of the first one) will hit the US economy in 2020Q4 ("second wave scenario"). We assume that the probability of the former (latter) is 75 (25) percent. In both scenarios, monetary policy shocks are wangled in order to respect the Effective Lower Bound (ELB) until the first quarter of 2023.

The estimated COVID-19 shock in 2020Q2 is extremely large and explains the deep trough in 2020Q2 as well as the strong rebound in 2020Q3. The recovery in the second half of the year however is not sufficient to bring output growth in positive territory yielding a Q4/Q4 GDP growth of -2.3 percent in 2020. It is important to highlight that the second wave scenario build in our combined forecast contributes to the negative growth number in 2020 and adds momentum in 2021. The economy rebounds in 2021 where we forecast GDP growth at 4.0 percent. While most of the economic recovery starting in the third quarter of 2020 is COVID-19 induced (i.e. the result of progressively relaxing the social distancing measures), part of it is also explained by a positive technology shock. Moreover, even if constrained by the ELB in 2020, monetary policy remains supportive of growth. In fact, the expectations that the federal funds rate will remain at the ELB until the first half of 2023 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 drag for the real economy in 2022 and 2023. As a result, the model forecasts GDP growth at 1.5 percent in 2022 and 1.4 percent in 2023.

The forecast for Q4/Q4 core PCE inflation is substantially below target in 2020, i.e. at 0.8 percent. The temporary weakness in inflation comes from both negative markup shocks and discount factor shocks (increase in the desire to save); these deflationary forces are counterbalanced by the supply side of the COVID-19 shock that exerts a positive upward pressure on inflation. As a result, inflation is expected to rise modestly in 2021 approaching 1.8 percent. In the medium term however, inflation is forecast to remain at subdued levels, settling at 1.5 percent in 2022 and 2023. This is mostly due to the effect of the estimated positive technology shock in 2020Q3, which push inflation down in the medium term.

Fluctuations in the natural rate are huge and entirely driven by the COVID-19 shock. Since the magnitude of the COVID-19 shock is estimated to be extremely large by any historical standards, the estimated drop of the natural rate 2020 is very pronounced, much larger than any historical records. In particular, the model forecasts that the (real) natural rate of interest at the end of the year for 2020 through 2023 will equal -16.7 percent, -1.2 percent, -1.2 percent, and -0.5 percent respectively. The model sees that the output gap will not close throughout the entire forecasting horizon; we forecast end-of-year output gaps for 2020 through 2023, at -2.5 percent, -1.2 percent, -1.4 percent and -1.6 percent respectively.

The uncertainty surrounding these forecasts is very large.