BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF MONETARY AFFAIRS

FOMC SECRETARIAT

Date: December 7, 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

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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), 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 induced recession has proven challenging to rationalize with existing DSGE models. The dramatic fall in output growth in the second quarter, as well as the growth surge in the third quarter are unprecedented in the data samples used to construct and estimate the models. Social distancing responses to the seeming multiple waves of the pandemic and the resulting effects on economic activity remain difficult to anticipate. The propagation of the COVID-19 disruption has been very fast and most likely very different from the typical transmission of business cycles shocks. Consequently, forecasting the economic effects of COVID-19 going forward is problematic and the degree of uncertainty surrounding the forecasts remains very high.

As has been the case for the previous two forecast rounds the models confront the challenges associated with the COVID-19 pandemic by incorporating external information, adding new shocks, or both. The New York Fed and Chicago Fed use Survey of Professional Forecasters expectations about the near-term GDP (and inflation, in the case of Chicago) projections to inform their forecasts. 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.

Some of the modelers assess that the pre-COVID set of shocks, whose stochastic properties were estimated using a sample that did not contain disturbances of the magnitude of COVID-19, are not sufficient to capture the size and persistence of the pandemic's effects. For this reason, the Philadelphia, Chicago and New York Fed introduced new shocks to help account for 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.

As in the previous round, the modelers take measures to reflect the elevated degree of uncertainty surrounding the forecasts, stemming from the paucity of information about the channels of transmission of the shock, or the magnitude of the second wave 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 and the New York Fed consider an alternative scenario where the second wave of virus has a significant negative impact on growth in the winter months.

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 December Tealbook forecasts, as well as the DSGE model forecasts prepared for the September 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 low of -2.6 percent (Philadelphia and New York) to a high of 0.2 percent (Chicago). The median forecast is at -2.5 percent, up one percentage point from September and reflecting the stronger-than-expected data early in the fourth quarter. The dispersion across point forecasts[2] for 2020 is somewhat higher compared to September, though forecast uncertainty is lower. All the models predict stronger growth in 2021, though to varying degrees. New York is the most optimistic (6.3 percent) while Philadelphia is the least (1.9 percent). The median value across models is at 3.8 percent, down a bit from 4.7 percent in September. Uncertainty remains elevated and both Chicago and Philadelphia have 68 percent coverage intervals that include negative growth. For all the models but Philadelphia, growth in 2022 decelerates generating a median GDP growth of 2.5 percent

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

(compared to 3.2 percent in September). In 2023 median growth is 2.4 percent, about unchanged from September.

In terms of inflation forecasts, all models agree that inflation will be below the FOMC's long run goal; beyond 2020 the median projections are similar compared to September, but the details are a bit different. Philadelphia has revised up its inflation projection for 2021, while the other models see lower inflation next year compared to September. The broader picture though is that inflation remains subdued throughout the forecast horizon with a median point forecast for 2021 through 2023 of 0.9 percent, 1.2 percent and 1.5 percent respectively. In general, the models see little chance of deflation with only a few of the coverage intervals including negative numbers --- and then only barely. This is due to the flat Phillips curve that is estimated in these models.

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 sees the federal funds rate rising to about 1 percent by the end of 2022. New York has implemented a flexible average inflation targeting rule this round and so now sees the funds rate rising in 2023. Chicago sees the federal funds rate rising in 2023 as well and PRISM continues to peg the federal funds rate at the ELB through the end of 2023.

For all the models the natural rate of interest fell (in some 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 -10.6 percent (Chicago Fed) to 0.8 percent (EDO). Towards the end of the forecast horizon, the natural rate of interest turns positive for three out of four models and the median stands at 1 percent.

Finally, all models see a negative output gap in the current quarter, with actual output being from 4.7 to 0.7 percent below natural output. For all the models the gap shrinks over the forecast horizon but nonetheless remains generally negative.

[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.

Forecasts

Model	Output Growth (Q4/Q4)							
	2020		2021		2022		2023	
	December	*September*	**December**	*September*	**December**	*September*	**December**	*September*
EDO - Board of Governors	**-2.3** **(-2.3, -2.3)**	*-2.9* *(-3.8, -1.9)*	**4.4** **(2.0, 6.7)**	*5.4* *(2.8, 8.1)*	**2.4** **(0.1, 4.8)**	*3.1* *(0.7, 5.6)*	**2.8** **(0.7, 5.0)**	*1.1* *(-1.1, 3.2)*
New York Fed	**-2.6** **(-3.4, -1.8)**	*-4.1* *(-5.7, -3)*	**6.3** **(4.1, 8.4)**	*5.9* *(1.9, 8.1)*	**3.0** **(1.8, 4.3)**	*4.4* *(1.2, 7.1)*	**2.1** **(-0.4, 3.4)**	*3.9* *(1.2, 7)*
PRISM - Philadelphia Fed	**-2.6** **(-2.6, -2.6)**	*-4.1* *(-6.6, -1.6)*	**1.9** **(-1.3, 5.0)**	*2.7* *(-3.5, 9)*	**2.6** **(-1.5, 6.3)**	*3.4* *(-4.3, 11)*	**2.6** **(-1.4, 6.4)**	*3.3* *(0.8, 5.7)*
Chicago Fed	**0.2** **(0.2, 0.2)**	*-2.3* *(-4.8, -0.2)*	**3.1** **(-7.2, 13.4)**	*4.1* *(-1.3, 9.4)*	**1.5** **(-10.8, 13.9)**	*1.5* *(-3.7, 6.6)*	**1.6** **(-11.2, 14.3)**	*1.4* *(-4, 6.9)*
Median Forecast*	**-2.5**	*-3.5*	**3.8**	*4.7*	**2.5**	*3.2*	**2.4**	*2.3*
December Tealbook	**-2.3**		**4.3**		**3.5**		**2.3**	

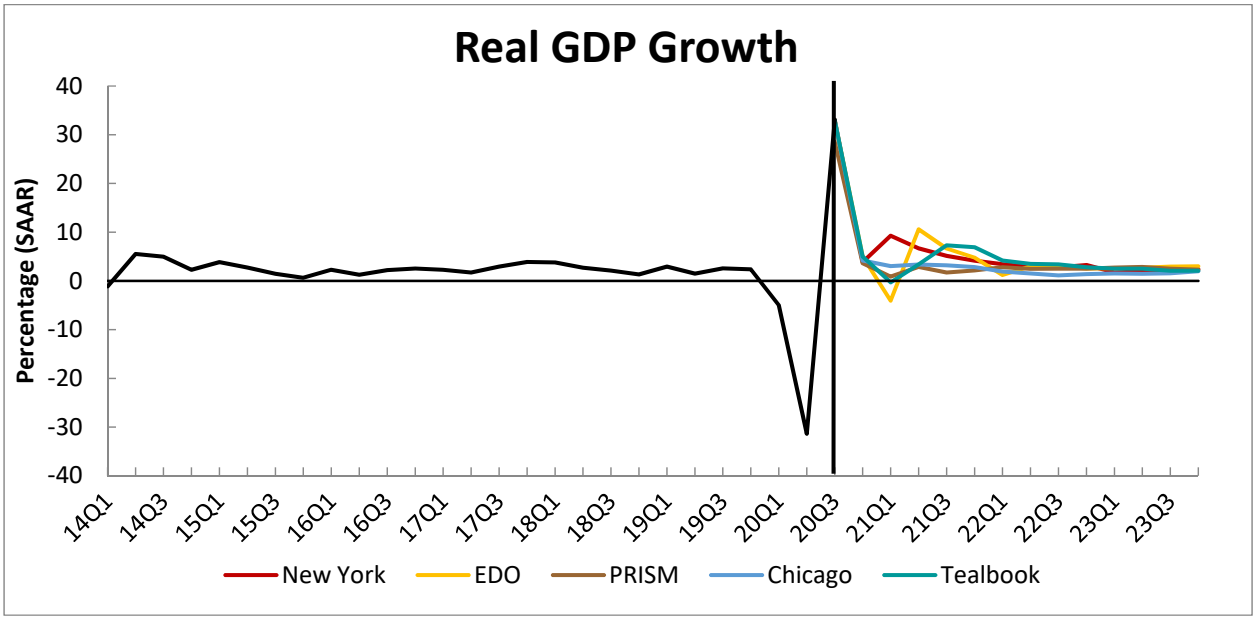
Model	Core PCE Inflation (Q4/Q4)							
	2020		2021		2022		2023	
	December	*September*	**December**	*September*	**December**	*September*	**December**	*September*
EDO - Board of Governors	**1.4** **(1.4, 1.4)**	*1.5* *(1.4, 1.6)*	**0.5** **(-0.2, 1.1)**	*1.4* *(0.7, 2.1)*	**0.6** **(-0.3, 1.6)**	*1.3* *(0.3, 2.3)*	**1.3** **(0.4, 2.3)**	*1.5* *(0.5, 2.6)*
New York Fed	**1.3** **(1.1, 1.5)**	*0.8* *(0.6, 1)*	**0.5** **(-0.3, 1.3)**	*0.7* *(-0.2, 1.6)*	**0.8** **(-0.3, 1.9)**	*1.0* *(-0.1, 2.1)*	**1.1** **(-0.1, 2.4)**	*1.3* *(0.1, 2.6)*
PRISM - Philadelphia Fed	**1.6** **(1.6, 1.6)**	*0.6* *(0.1, 1.1)*	**1.7** **(0.6, 2.9)**	*0.3* *(-1.8, 2.4)*	**1.6** **(0.0, 3.2)**	*0.9* *(-0.2, 2.1)*	**1.7** **(-0.2, 3.7)**	*1.5* *(-0.2, 3.1)*
Chicago Fed	**1.4** **(1.4, 1.4)**	*0.8* *(0.5, 1.1)*	**1.3** **(0.0, 2.5)**	*1.8* *(0.5, 3)*	**1.6** **(0.2, 3.0)**	*1.5* *(0.3, 2.8)*	**1.7** **(0.3, 3.2)**	*1.5* *(0.3, 2.7)*
Median Forecast*	**1.4**	*0.8*	**0.9**	*1.0*	**1.2**	*1.2*	**1.5**	*1.5*
December Tealbook	**1.4**		**1.8**		**1.8**		**1.9**	

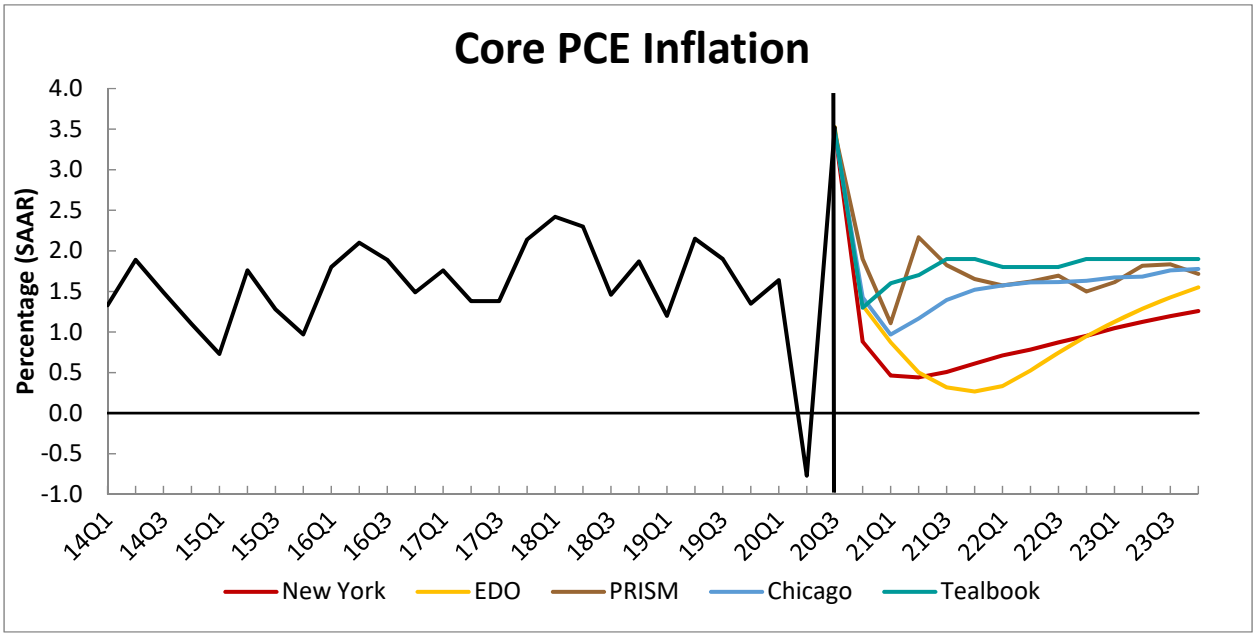
Model	Federal Funds Rate (Q4)							
	2020		2021		2022		2023	
	December	*September*	December	*September*	December	*September*	December	*September*
EDO - Board of Governors	**0.1** **(0.1, 0.1)**	*0.1* *(0.1, 0.1)*	**0.1** **(0.1, 0.1)**	*0.1* *(0.1, 0.1)*	**1.1** **(0.1, 2.1)**	*0.9* *(0.1, 1.6)*	**2.2** **(0.5, 3.9)**	*2.2* *(0.6, 3.8)*
New York Fed	**0.1** **(0.1, 0.1)**	*0.1* *(0.1, 0.8)*	**0.1** **(0.1, 0.1)**	*0.1* *(0.1, 1.7)*	**0.1** **(0.1, 0.1)**	*1.1* *(0.2, 3)*	**1.1** **(0.1, 3.5)**	*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)**	*0.1* *(0.1, 0.1)*
Chicago Fed	**0.1** **(0.1, 0.1)**	*0.1* *(0.1, 0.2)*	**0.1** **(0.1, 0.2)**	*0.1* *(0.1, 0.2)*	**0.1** **(0.1, 0.2)**	*0.1* *(0.1, 0.1)*	**0.6** **(-0.8, 2.0)**	*1.1* *(-0.7, 3.1)*
Median Forecast*	**0.1**	*0.1*	**0.1**	*0.1*	**0.1**	*0.5*	**0.9**	*1.6*
December Tealbook	**0.1**		**0.1**		**0.1**		**0.1**	

Model	Real Natural Rate of Interest r* (Q4)							
	2020		2021		2022		2023	
	December	*September*	December	*September*	December	*September*	December	*September*
EDO - Board of Governors	**0.8** **(-1.4, 3.0)**	*7.8* *(2.3, 13.4)*	**-4.4** **(-11.4, 3.0)**	*0.1* *(-10.1, 9.9)*	**2.1** **(-3.0, 6.9)**	*-2.4* *(-7.6, 2.7)*	**2.4** **(-2.4, 7.2)**	*1.1* *(-3.8, 6)*
New York Fed	**-7.8** **(-10.8, -4.8)**	*-3.7* *(-6.7, -0.7)*	**-0.6** **(-2.1, 0.9)**	*-1.5* *(-3, 0)*	**0.0** **(-1.6, 1.6)**	*-0.5* *(-2.1, 1.2)*	**0.2** **(-1.4, 1.9)**	*0.2* *(-1.5, 1.9)*
PRISM - Philadelphia Fed	**-2.1** **(-14.8, 10.8)**	*-4.8* *(-11, 1.5)*	**1.4** **(-5.5, 7.8)**	*-0.5* *(-10, 8.9)*	**1.3** **(-4.0, 6.9)**	*0.7* *(-7.9, 9.3)*	**1.8** **(-5.0, 8.2)**	*1.5* *(-4.8, 7.8)*
Chicago Fed	**-10.6** **(-10.6, -10.6)**	*-16.7* *(-50.6, -2.1)*	**-0.5** **(-39.8, 37.7)**	*-1.2* *(-8.3, 5.9)*	**-2.0** **(-45.2, 41.4)**	*-1.2* *(-8.5, 6.1)*	**-0.5** **(-43.1, 41.2)**	*-0.5* *(-7.6, 6.7)*
Median Forecast*	**-5.0**	*-4.2*	**-0.6**	*-0.9*	**0.7**	*-0.8*	**1.0**	*0.6*

Model	Output Gap (Q4)							
	2020		2021		2022		2023	
	December	*September*	**December**	*September*	**December**	*September*	**December**	*September*
EDO - Board of Governors	**-4.1 (-4.5, -3.7)**	*-2.2 (-3.1, -1.4)*	**-2.1 (-4.1, -0.2)**	*2.3 (-0.2, 4.7)*	**-2.2 (-5.0, 0.6)**	*2.1 (-1, 5.1)*	**-1.3 (-3.9, 1.3)**	*0.9 (-2, 3.7)*
New York Fed	**-4.7 (-6.3, -3.1)**	*-5.6 (-7.5, -4.1)*	**-0.9 (-3.5, 1.8)**	*-3.4 (-7.2, -1.7)*	**0.0 (-2.8, 2.8)**	*-2.3 (-7.2, 0)*	**-0.1 (-3.5, 2.0)**	*-1.4 (-6.4, 1.6)*
PRISM - Philadelphia Fed	**-0.7 (-1.2, 0.0)**	*-1.0 (-1.8, -0.2)*	**-0.6 (-1.6, 0.3)**	*-1.1 (-2, -0.2)*	**-0.6 (-1.8, 0.7)**	*-0.7 (-1.9, 0.5)*	**-0.3 (-2.2, 1.8)**	*-0.3 (-2, 1.3)*
Chicago Fed	**-3.4 (-3.4, -3.4)**	*-2.5 (-3.6, -1.5)*	**-3.2 (-6.0, -0.4)**	*-1.2 (-4.1, 1.7)*	**-2.8 (-7.3, 1.6)**	*-1.4 (-4.6, 1.7)*	**-2.5 (-4.5, 1.2)**	*-1.6 (-4.5, 1.2)*
Median Forecast*	**-3.8**	*-2.4*	**-1.5**	*-1.2*	**-1.4**	*-1.1*	**-0.8**	*-0.8*
December Tealbook	**-0.6**		**0.6**		**2.1**		**2.6**	

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)
40
30
20
10
0
-10
-20
-30
-40
14Q1
14Q3
15Q1
15Q3
16Q1
16Q3
17Q1
17Q3
18Q1
18Q3
19Q1
19Q3
20Q1
20Q3
21Q1
21Q3
22Q1
22Q3
23Q1
23Q3
New York
EDO
PRISM
Chicago
Tealbook


Core PCE Inflation
Percentage (SAAR)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
14Q1
14Q3
15Q1
15Q3
16Q1
16Q3
17Q1
17Q3
18Q1
18Q3
19Q1
19Q3
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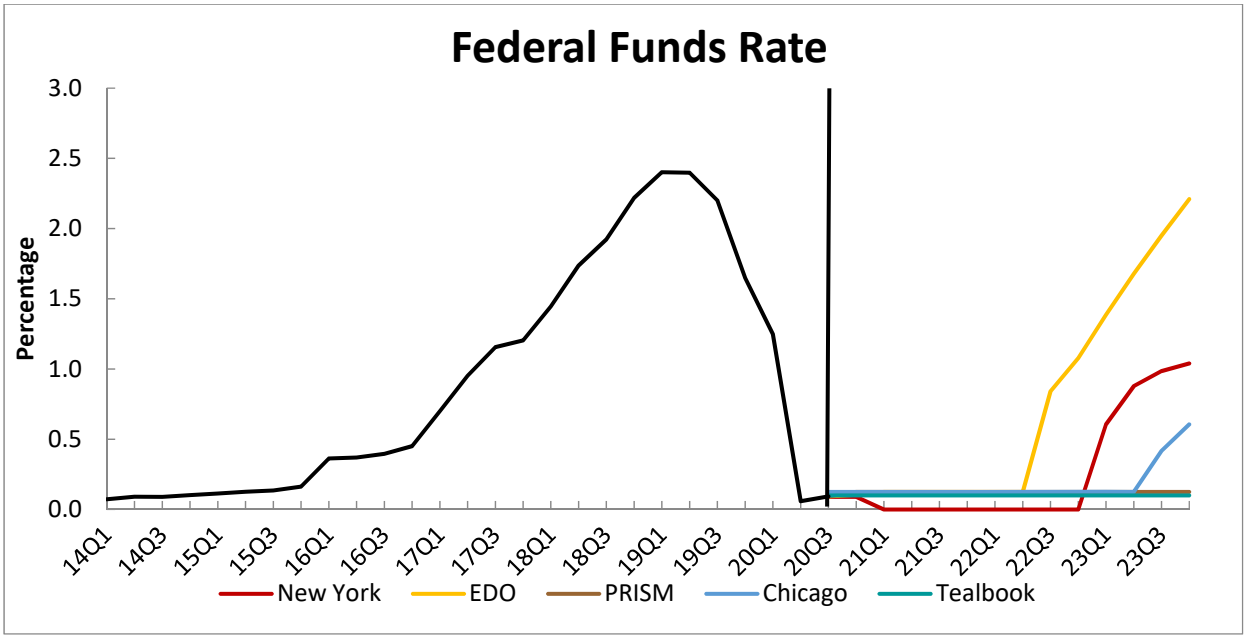
22Q1
22Q3
23Q1
23Q3
New York
EDO
PRISM
Chicago
Tealbook


Federal Funds Rate
Percentage
3.0
2.5
2.0
1.5
1.0
0.5
0.0
14Q1
14Q3
15Q1
15Q3
16Q1
16Q3
17Q1
17Q3
18Q1
18Q3
19Q1
19Q3
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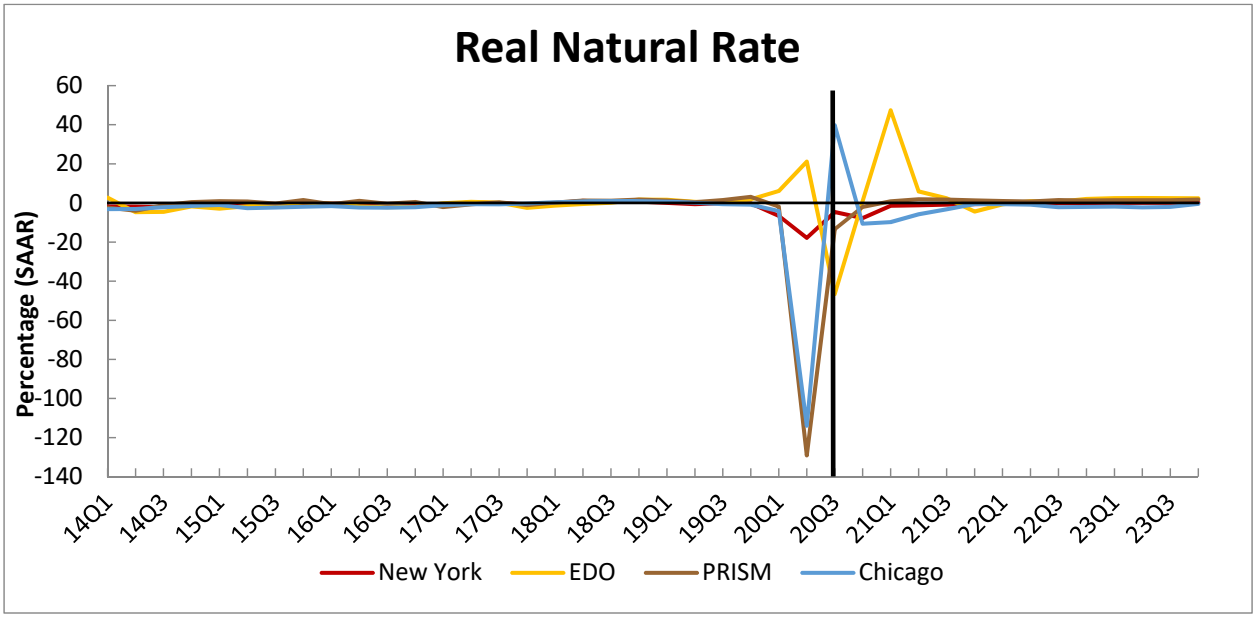
22Q1
22Q3
23Q1
23Q3
New York
EDO
PRISM
Chicago
Tealbook


Real Natural Rate
Percentage (SAAR)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
14Q1
14Q3
15Q1
15Q3
16Q1
16Q3
17Q1
17Q3
18Q1
18Q3
19Q1
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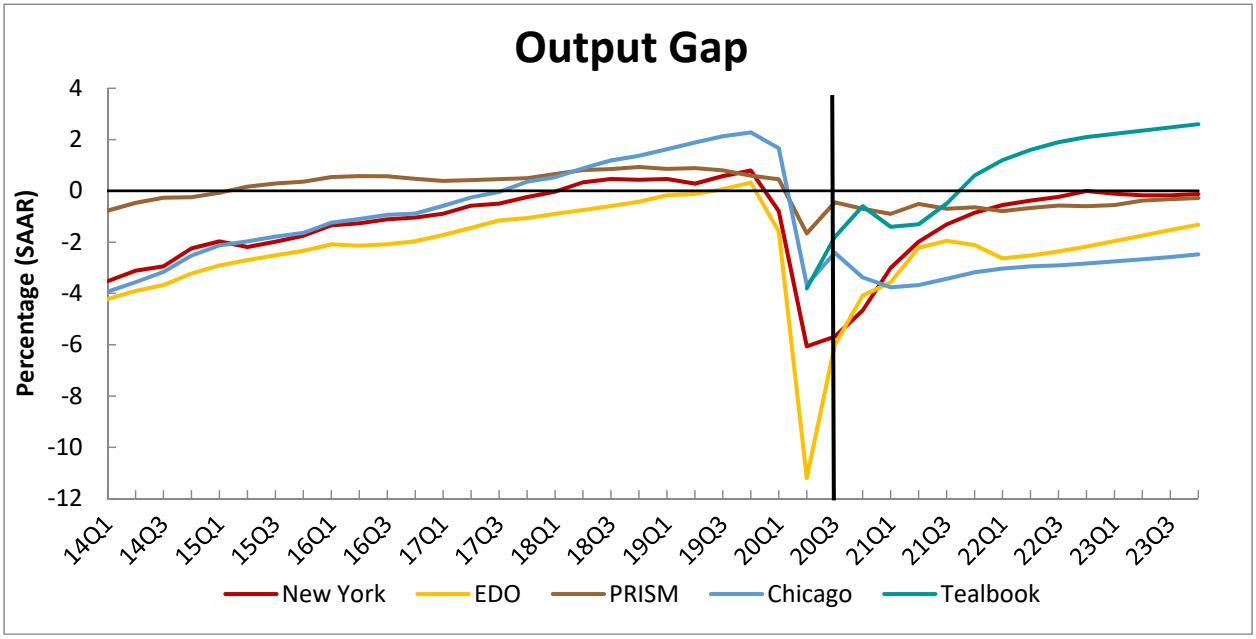
21Q3
22Q1
22Q3
23Q1
23Q3
New York
EDO
PRISM
Chicago


Output Gap
Percentage (SAAR)
4
2
0
-2
-4
-6
-8
-10
-12
14Q1
14Q3
15Q1
15Q3
16Q1
16Q3
17Q1
17Q3
18Q1
18Q3
19Q1
19Q3
20Q1
20Q3
21Q1
21Q3
22Q1
22Q3
23Q1
23Q3
New York
EDO
PRISM
Chicago
Tealbook

Detailed Descriptions of Individual Model Forecasts

The EDO Model

Reflecting the huge movements in economic activity in the data for 2020:Q2 and the staff's nowcast for 2020:Q4—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 2.3 percent this year and then to rebound 4.4 percent in 2021. Inflation is below 1 percent each year until 2022 and reaches only 1.4 percent by the end of 2023. The federal funds rate remains at the effective lower bound (ELB) until the middle 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 to 2020:Q4 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:Q1.

With the federal funds rate at the ELB in 2020:Q2, we also assume that the public in that quarter expects the federal funds rate to remain at the ELB until mid-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 September, 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 trigger renewed bouts of intense social distancing, we assume that a severe second wave of

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

economic restrictions may begin in 2021:Q1 with a 25 percent probability; the course of the second wave follows that of the first, but between zero and one-third times as large, with a uniformly distributed scale. This assumption implies that the distribution of outcomes is adversely biased relative to the modal forecast, while the tails of the distribution are adversely skewed. 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 the middle of 2022 without reference to particular exit conditions. Although inflation remains low in 2022, the federal funds rate exits the ELB immediately as soon as the estimated rule assumes control and rises above one percent by the end of the year.

The NY Fed Model

The New York Fed model forecasts are obtained using data released through 2020Q3. As mentioned in previous memos, in order to address the implications of the COVID-19 shock 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. 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 model explains the decline in economic activity in 2020Q1 and Q2 using predominantly these transitory shocks.

For this round of forecasts two further changes were made to the model. First, the model incorporates an additional COVID-19 demand shock taking place in 2020Q4 but anticipated in Q3. This shock captures the renewed weakness in demand in the current quarter stemming from the second wave of the pandemic, and its size is disciplined by imposing that the Q3 expectation for real GDP growth in Q4 coincides with the median forecast from the November Philadelphia Fed Survey of Professional Forecasters (henceforth, SPF), namely 4.00 percent, annualized. We also consider a second more pessimistic scenario where we impose that expected real GDP growth in Q4 coincides with the 10^{th} percentile of the cross-sectional distribution of SPF point forecasts (1.2 percent, annualized). The two scenarios are combined using weights (80, and 20

percent, respectively) that are loosely informed by the SPF average probability distribution for 2020 year-over-year real GDP growth.

Second, the model replaces the historical policy reaction function with a new reaction function, average inflation targeting (AIT), reflecting the changes in the FOMC monetary policy strategy announced last August. In our implementation, the interest rate reacts to a moving average (MA) of deviations of PCE inflation from the FOMC long run goal of 2 percent, where the MA half-life is 10 quarters. It also reacts to an MA of deviations of output growth from its steady state value in light of both the Federal Reserve's dual mandate and the central bank's intention to support the recovery from the COVID-19 recession. Finally, the new reaction function features inertia, like the old one. The reaction function parameters were chosen so that the liftoff of interest rates from the ELB would take place in early 2023, and would be very gradual. Importantly, the model assumes that the introduction of the new reaction function is only partially incorporated by the agents in forming expectations. Specifically, agents' expectations are formed using a convex combination of projections obtained under the old and new reaction functions using weights of 2/3 and 1/3, respectively. This approach reflects the fact that households' and firms' expectations may adjust slowly to the introduction of the new policy strategy.

In the forecast that combines the two scenarios described above real GDP growth is expected to be -2.6 percent in 2020 on a Q4/Q4 basis, compared with a -4.1 percent projection in September. The introduction of AIT tends to accelerate the recovery so that growth in 2021 is a bit faster than predicted in September (6.2 versus 5.9 percent), but slower in 2022 (3.1 versus 4.4 percent) and 2023 (2.1 versus 3.9 percent). Core inflation is projected to be 1.3 percent in 2020, above the September forecast of 0.8 percent, but in spite of AIT it is expected to remain subdued throughout the forecast horizon, and below the projections in September. The change in the inflation projections relative to September mostly reflects the fact that the model is now more certain in interpreting the COVID-19 recession as a demand shock, leading to a decline in inflation. *Ceteris paribus*, AIT lifts the inflation projections by roughly 20 basis points relative to the forecast under the historical reaction function. Nonetheless, the small estimated slope of the Phillips curve implies that AIT has a limited impact on inflation, even if it boosts the recovery. The uncertainty surrounding the projections for all variables is generally lower than in the September forecasts, and much lower than in June.

Partly because of the second wave of the pandemic, the real natural rate falls temporarily by a large amount, -7.8 percent, in 2020Q4 but it rebounds faster in 2021than it did in the September projections, reflecting the transitory nature of the shocks. The output gap is estimated to be negative in 2020 at -4.7 percent, but it is projected to rise faster than in the September forecast, closing by 2022.

The Philadelphia Model

The Philadelphia forecast is constructed using data through 2020Q3 that are then supplemented with a 2020Q4 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. Our assumptions about fiscal and monetary policy are largely unchanged but we have continued to use 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 three quarters. In our view, aggregate demand dropped as consumers experienced a short-lived increase in patience and found it harder to transform final goods to capital. Lower costs of vacancy creation are a stand-in for forces that kept employment high relative to the level of demand.

The nowcast for 2020Q4 sets real GDP growth at 3.7 percent at an annual rate, the unemployment rate at 6.8 percent, core inflation at 1.9 percent, and the federal funds rate at 0.12 percent. Under this nowcast, the model generates an output gap of -0.7 percent and an rstar of -2.1 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 0.9 percent in 2021Q1 and then rebound to 2.9 percent growth in Q2. For 2021 as a whole, real GDP growth is projected to be -1.9 percent. Growth then accelerates to about 2.5 percent in 2022 and 2023. In general though, the path for future growth this forecast round is lower than the path we projected in September, after an upward revision to growth in 2020. Under our current projection, the economy reaches its pre-pandemic level of real GDP in the summer of 2022. The forecast for inflation is revised up compared to September: Core PCE inflation is projected to average 1.7 percent in 2021, 1.6 percent in 2022, and 1.7 percent in 2023. The FFR is fixed at the ELB throughout the forecast horizon.

The unemployment rate declines gradually from 6.8 percent in the current quarter to 5.8 percent by the end of 2021, and falls to 5.1 percent by the end of 2023, almost one percentage above the natural rate of unemployment.

The natural rate of interest dropped sharply in the first half of 2020 in response to the combination of short-lived Covid shocks. As these shocks dissipate, rstar jumps from -129 percent at an annual rate in 2020Q2 to -2.1 percent in 2020Q4. Rstar continues to rise through the first half of 2021 in response to dissipating effects of Covid shocks. At the end of the forecast horizon in 2023Q4, the natural rate of interest is at 1.7 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 -0.7 percent in 2020Q4. The output gap continues to deteriorate over the near term to reach a low of -0.8 percent in 2022Q1. The output gap then begins to slowly improve and reaches -0.3 percent at the end of 2023.

According to the Philadelphia model, the output growth in 2020Q4 is largely driven by the rebound from the effect of Covid-related shocks in the previous two quarters. This effect carries forward over the forecast horizon, albeit to a lesser degree. Output growth over the remainder of the forecast horizon is attributed to various shocks, most notably smaller effects of prior Covid-related shocks, and monetary policy on the positive side, and TFP and mark-up shocks on the negative side. Consumption dynamics closely follow that of output, and are driven by TFP shocks and prior Covid-related shocks. The model attributes the dramatic rebound in Q2 investment growth to Covid shocks and investment shocks. These shocks are not very persistent though so over the next two quarters investment growth weakens enough to run slightly negative – pulled down by markup and TFP shocks --before rebounding to about 2 percent in 2021Q2. Thereafter, investment growth runs in a range of 2 to 3 percent through the end of 2023.

Core inflation is expected to run at a pace somewhat-below target pace over the forecast horizon. Factors pushing inflation down include Covid-related shocks, monetary policy that constrained by the ELB, and matching efficiency shocks. However, those shocks are largely offset by the effects of weak TFP growth and markup shocks, resulting in average core inflation of about 1.7 percent in 2021. The model does not incorporate an average inflation targeting rule as currently configured. The forecast calls for core inflation to run at a 1.6 percent pace in 2022 and a 1.7 percent pace in 2023, and so does not see above-target inflation being realized on any persistent basis over the next few years.

The forecast is implemented with the federal funds rate pegged at the ELB through the end of 2023.

To address heightened uncertainty, we inflate the uncertainty bands for all variables, except the fed funds rate and inflation, by the same factor that the standard errors of the Survey of Professional Forecasters density forecasts have risen between 2020Q1 and 2020Q4.

The Chicago Fed Model

The Chicago Fed DSGE model forecast is constructed using data through 2020Q3 supplemented by a number of assumptions based on market expectations, survey data and judgments for the fourth quarter of 2020. The assumption for GDP growth for 2020Q4 is 4.2 percent at an annualized rate based on IHS. The forecast also incorporates assumptions for the main components of GDP growth, consumption and investment, based on IHS forecasts and internal calculations. The federal fund rate is at the effective lower bound (ELB) and expected to stay there until the second semester of 2023, in line with the Survey of Market Participants. The conditioning assumptions also include expected CPI and PCE inflation over the next 10 years, taken from the fourth quarter Survey of Professional Forecasters (SPF). As in the previous round, our information set has been enriched 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. In particular, the COVID-19 shock is defined as a linear combination of shocks that typically play an important role in explaining business cycle fluctuations and inflation dynamics. These shocks are the liquidity preference shocks, the permanent neutral shocks, the shocks to the marginal efficiency of investment (MEI), the price markup shocks, and the discount factor shocks. Moreover, the economic effects of the COVID-19 shock are modeled as a set of surprise and anticipated i.i.d. shocks.

The identification of the parameters that determine the synthetic shock's size, nature and persistence is achieved through the use of expectations and narrative restrictions; i.e. by assuming that the COVID-19 shock 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.

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, 2020Q3 and 2020Q4 so as to maximize the likelihood function in each of these quarters. The relative loadings on various structural shocks, which define the COVID-19 shock, are analogously estimated, but for these parameters only 2020Q2 data are used.

The estimated COVID-19 shock turns out to explain the massive output contraction in the second quarter of the year and to largely explain the quick rebound in real activity in the third quarter. In the fourth quarter, the COVID-19 shock exerts a negative pressure on GDP growth albeit the size of it is smaller relative to the previous quarters. The recovery started in the second half of the year is sufficient to bring output growth in positive territory yielding a Q4/Q4 GDP growth of 0.2 percent in 2020. The economic rebound in 2020Q3 is also explained by a positive discount factor shock, which induces agents to save less and consume more, and a positive shock to the marginal efficiency of investment. This creates some momentum in 2021 where we forecast GDP growth at 3.2 percent. Over the medium term, however, the model see weakness and GDP growth is forecast to be below potential at 1.5 percent in 2022 and 1.6 percent in 2023.

Akin to GDP growth, PCE inflation has exhibited substantially volatility in 2020 relative to historical standards. These large swings in inflation, especially in the second and third quarters, are mostly explained by the COVID-19 and price markup shocks. Unlike markups shocks that are short lasting, the supply side of the COVID-19 shock exerts a longer lasting upward pressure on

inflation. This force is not strong enough to push inflation above target. As a result, the forecast for Q4/Q4 core PCE inflation is below target in 2020, i.e. at 1.4 percent, and in the medium term. In particular, inflation is forecast to remain at subdued levels over the forecasting horizon, i.e. settling at 1.3 percent in 2021, 1.6 percent in 2022 and 1.7 percent in 2023.

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 -10.6 percent, -0.5 percent, -2.0 percent, and -0.5 percent respectively. The model sees that a large output gap, which will not close throughout the entire forecasting horizon; we forecast end-of-year output gaps for 2020 through 2023, at -3.4 percent, -3.2 percent, -2.8 percent and -2.5 percent respectively.

The uncertainty surrounding these forecasts is very large.