Online Appendix for "The New Tools of Monetary Policy"

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This document is an appendix to "The New Tools of Monetary Policy." In section I, we describe the FRB/US simulation approach, model assumptions, and the specifications for the alternative monetary policies. In section II we report additional simulation results under alternative assumptions about the neutral interest rate and about how agents form their expectations.

## I. Description of the FRB/US simulations

### *A. Simulation approach and model assumptions*

The analysis presented in the lecture uses the Federal Reserve's FRB/US model of the U.S. economy.[1] We followed Kiley and Roberts (2017), Kiley (2018), and others in performing stochastic simulations of the model. Specifically, for each policy rule considered, we conducted 500 simulations of the model using shocks drawn with replacement from the model residuals over the period 1970 – 2015. In each run the model was simulated for 200 quarters. The results for the first 100 quarters of each simulation were used to establish appropriately random initial conditions, then discarded.

For the results presented in the main text, we simulated the model under the assumption that households, firms, and financial markets have forward-looking, model-consistent expectations (MCE). In this appendix, we also present results under the alternative assumption that only asset-market participants have model-consistent expectations (MCAP, for model-consistent asset pricing), while households and firms form their expectations in a backward-looking manner. Under the MCAP assumption, solutions for bond yields, exchange rates, and equity prices are consistent with the assumed monetary policy rule, but expectations of income and inflation are based on forecasts from small VAR systems which do not vary with the setting of policy. See Bernanke, Kiley, and Roberts (2019) for more discussion of these alternative expectational assumptions.

### *B. Specifications of alternative monetary policies*

As a baseline description of monetary policy, we used an inertial, Taylor-type policy rule. In simulations of alternative policies, monetary policy was assumed to follow the baseline rule whenever the prescribed policy rate is positive, except when overridden by forward guidance. Under the baseline rule, the notional (nominal) policy interest rate $i_t^*$ is determined by

$$i_t^* = 0.85 i_{t-1} + (1 - 0.85)[\mathrm{r}^* + \pi_t + 0.5(\pi_t - \pi^*) + \hat{y}_t] \quad (1)$$

where $\mathrm{r}^*$ is the real natural rate of interest (in the base case, either 1 or 0 percent), $\pi^*$ is the central bank's inflation target (in the base case, 2 percent), the inflation rate $\pi_t$ is defined to be the four-quarter percent

[1] For more discussion of FRB/US, see Brayton, Flint, Thomas Laubach, and David Reifschneider, "The FRB/US Model: A Tool for Macroeconomic Policy Analysis." FEDS Note, April 2014. https://www.federalreserve.gov/econresdata/notes/feds-notes/2014/a-tool-for-macroeconomic-policy-analysis.html

change in core PCE prices, and $\hat{y}$ is the (GDP) output gap.[2] The realized policy interest rate $i_t$ is constrained by an effective lower bound (ELB), taken in all these simulations to be zero:[3]

$$i_t = \max\{i_t^*, 0\} \tag{2}$$

In simulations of "unconstrained policy," we simply removed this constraint and allowed the policy rate to equal the notional rate, even when negative.

We simulated a set of threshold-based forward guidance policies, in which the central bank commits, upon encountering the ELB, to defer lift-off until inflation is sufficiently high. Once an inflation threshold has been met, the interest rate rule returns to the path prescribed by the inertial Taylor rule (1). We considered inflation thresholds of 1¾, 2, and 2¼ percent, as in Chung and coauthors (2019).

We assumed that forward guidance is credible for a maximum of 7 years, meaning the central bank cannot commit to a policy other than the baseline policy for more than 7 years from the point at which the ELB first binds. Agents were assumed to expect that, after 7 years, policy will revert to the Taylor-rule baseline, constrained by the ELB.

In addition, we simulated the effects of the four quantitative easing (QE) programs studied by Kiley (2018). Our specifications of the QE programs were taken directly from that study, which should be consulted for details. In general, Kiley modeled QE policies in the following manner: Upon meeting some economic condition, for example, that the output gap is sufficiently negative, the central bank begins purchasing Treasury securities at a specified rate as long as that condition holds. The central bank's balance sheet is assumed to evolve according to an AR(2) process:

$$A_t = 1.6A_{t-1} - 0.62A_{t-2} + QE_t \tag{3}$$

where $A_t$ is the stock of assets and $QE_t$ is the flow of current asset purchases in quarter $t$, both in billions of dollars. The AR process implies that the total stock of assets peaks about 1 year after the initiation of purchases ($QE$) and declines thereafter at roughly 5 percent per quarter.

Following Kiley (2018) and Reifschneider (2016), we assumed that the effects of a given QE program on long-term Treasury term premiums are directly proportional to the contemporaneous stock of assets. Like these authors, we took estimates from Engen, Laubach, and Reifschneider (2015), according to which each addition of $500 billion of 10-year Treasury securities to the central bank's portfolio reduces the term premiums on 5-year, 10-year, and 30-year Treasuries by 17, 20, and 7 basis points respectively.[4] These estimates are also consistent with those reported in the survey by Gagnon (2016). In FRB/US, these declines pass through fully to other asset prices and yields, including the yields on corporate bonds, real equity returns, and mortgage rates. As Kiley (2018) discussed, previous research has demonstrated a strong pass-through from QE-induced changes in term premiums on Treasury securities to private-sector yields (e.g. Engen, Laubach, and Reifschneider 2015). See Kiley (2018) for further discussion of the transmission of QE to income and spending in the FRB/US model.

The four QE policies we consider from Kiley (2018) are described in the grid below.

| **QE(A)** | **QE(C)** |
|---|---|
| Initiation: Purchases start when $\hat{y}_t < -5$. | Initiation: Purchases start when $\hat{y}_t < -2.5$. |

[2] The output gap is computed as 100*log(actual/potential), with potential defined as in FRB/US.
[3] As in Kiley and Roberts (2017) and Bernanke, Kiley and Roberts (2019), agents can expect the ELB to bind for a maximum of 60 quarters. Thereafter, agents expect the policy rate to follow the notional rate (1).
[4] The $500 billion is roughly in 2014 dollars – roughly, because it draws from several empirical sources.

Size: $QE_t$ is \$25 billion per quarter per unit of $\hat{y}_t < -5$.

$$QE_t = 25(-5 - \hat{y}_t)$$

Size: $QE_t$ is \$25 billion per quarter per unit of $\hat{y}_t < -2.5$.

$$QE_t = 25(-2.5 - \hat{y}_t)$$

**QE(B)**

Initiation: Purchases start when $\hat{y}_t < -5$.

Size: $QE_t$ is \$50 billion per quarter per unit of $\hat{y}_t < -5$.

$$QE_t = 50(-5 - \hat{y}_t)$$

**QE(D)**

Initiation: Purchases start when $\hat{y}_t < -2.5$.

Size: $QE_t$ is \$50 billion per quarter per unit of $\hat{y}_t < -2.5$.

$$QE_t = 50(-2.5 - \hat{y}_t)$$

Finally, we simulated three policies that combine forward guidance based on a 2 percent inflation threshold with QE(B), QE(C), and QE(D) described above. In these simulations, agents' expected date of the first interest rate increase prescribed by the forward guidance rule varies to be consistent with the economic improvement induced by QE. As a result, ELB episodes tend to be longer than under QE-only policies but shorter than under forward guidance-only policies.

Throughout our simulations, as in much of the literature, we assumed the existence of an emergency fiscal stimulus package that prevents the emergence of extremely adverse outcomes. Specifically, following Kiley and Roberts (2017), we assumed that government purchases expand when the output gap falls below -10 percentage points. The fiscal package is rarely triggered in our simulations, and its exclusion does not meaningfully change the results.

## II. Simulation results under alternative assumptions

### *A. Lower neutral interest rate*

Most estimates for the United States suggest the current level of the *nominal* neutral interest rate (i*) is in the range of 2-3 percent, implying, with expected inflation around 2 percent, a real neutral rate of between 0 and 1 percent. As discussed in the main text, however, some studies suggest the real neutral rate (r*) could be lower than zero.[5] The table below reports results from stochastic simulations of selected alternative policies under the assumption that the real neutral interest rate is –1 percent. The simulations continue to show substantial benefits from using the new monetary tools, relative to baseline policies that make no use of these tools. However, the losses for all policies are greater than those of the (hypothetical) unconstrained policy, implying that even active use of the new tools cannot fully compensate for the constraint of the lower bound under this assumption about r*. Moreover, when r* = -1, the economy spends a large fraction of time at the effective lower bound of zero, even with the use of the new monetary tools.

Table 5: Performance of Alternative Policies in Stochastic Simulations

| | **r* = -1** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mean Loss | Mean Unemploy-ment Gap | Mean Inflation | ELB Frequency | Mean ELB Duration | Mean Stock of Assets($B) | Mean Peak Stock of Assets($B) |
| *Panel A: Baseline Rules* | | | | | | | |
| Taylor, π*=2 | 21.2 | 2.0 | -0.6 | 79.4 | 38.5 | 0.0 | 0.0 |
| Taylor, π*=4 | 9.8 | 0.7 | 2.9 | 32.8 | 16.3 | 0.0 | 0.0 |
| Taylor, π*=5 | 6.1 | 0.3 | 4.6 | 13.7 | 11.6 | 0.0 | 0.0 |
| Taylor, Unconstrained π*=2 | 3.3 | 0.0 | 2.0 | -- | -- | 0.0 | 0.0 |
| *Panel B: Threshold-based Forward Guidance,* π*=2 | | | | | | | |
| Inflation > 2 | 19.8 | 1.8 | -0.4 | 79.9 | 38.8 | 0.0 | 0.0 |
| *Panel C: Quantitative Easing,* π*=2 | | | | | | | |
| QE (D) | 5.6 | 0.4 | 1.2 | 47.6 | 15.4 | 1,445 | 4,791 |
| *Panel D: Forward Guidance + Quantitative Easing,* π*=2 | | | | | | | |
| Inflation > 2 + QE (D) | 5.1 | 0.2 | 1.5 | 52.1 | 16.2 | 1,307 | 4,467 |

[5] See, for instance, Kiley (2019).

### *B. MCAP expectations*

The findings in the main text assume that all agents understand forward guidance and QE and incorporate the policies' effects on the economy into their forecasts. This assumption could lead us to overstate the effectiveness of alternative policies if households in fact form their expectations without regard to the policy framework. To check how much this assumption affects the long-run performance under alternative policies, we performed stochastic simulations under the alternative assumption that households and firms form their expectations in a backwards-looking manner, modeled by small-scale VARs, even as asset-market participants are forward-looking (MCAP). Tables 6 and 7 report results for selected policies under this assumption, for the cases in which the r* = 1 and r* = 0, respectively. These results can be compared to Tables 3 and 4 in the text, which assume model-consistent expectations by all agents. Making the alternative assumption about expectations formation does not change the broad conclusions of the study. Under the MCAP assumption, forward guidance becomes somewhat less effective (not surprisingly), but QE becomes slightly more effective. The combination of QE and forward guidance still largely compensates for the effects of the ELB, adding about three percentage points of policy space.

Table 6: Performance of Alternative Policies in Stochastic Simulations, MCAP

| **r* = 1** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mean Loss | Mean Unemploy-ment Gap | Mean Inflation | ELB Frequency | Mean ELB Duration | Mean Stock of Assets($B) | Mean Peak Stock of Assets($B) |
| *Panel A: Baseline Rules* | | | | | | | |
| Taylor, π*=2 | 11.2 | 1.3 | 1.2 | 39.9 | 25.5 | 0.0 | 0.0 |
| Taylor, π*=4 | 4.6 | 0.4 | 3.8 | 12.3 | 16.9 | 0.0 | 0.0 |
| Taylor, π*=5 | 3.6 | 0.2 | 4.9 | 5.0 | 13.2 | 0.0 | 0.0 |
| Taylor, Unconstrained π*=2 | 2.8 | 0.0 | 2.0 | - | - | 0.0 | 0.0 |
| *Panel B: Threshold-based Forward Guidance,* π*=2 | | | | | | | |
| Inflation > 2 | 9.4 | 0.8 | 1.6 | 38.1 | 29.8 | 0.0 | 0.0 |
| *Panel C: Quantitative Easing,* π*=2 | | | | | | | |
| QE (D) | 2.9 | 0.0 | 2.0 | 12.2 | 10.1 | 938 | 3,268 |
| *Panel D: Forward Guidance + Quantitative Easing,* π*=2 | | | | | | | |
| Inflation > 2 + QE (D) | 2.6 | -0.5 | 2.3 | 16.1 | 15.3 | 699 | 2,621 |

Table 7: Performance of Alternative Policies in Stochastic Simulations, MCAP

| **r* = 0** | Mean Loss | Mean Unemploy-ment Gap | Mean Inflation | ELB Frequency | Mean ELB Duration | Mean Stock of Assets($B) | Mean Peak Stock of Assets($B) |
|---|---|---|---|---|---|---|---|
| *Panel A: Baseline Rules* | | | | | | | |
| Taylor, π*=2 | 20.0 | 2.2 | 0.7 | 59.6 | 34.3 | 0.0 | 0.0 |
| Taylor, π*=4 | 7.0 | 0.8 | 3.5 | 23.6 | 22.2 | 0.0 | 0.0 |
| Taylor, π*=2 | 4.6 | 0.4 | 4.8 | 12.3 | 16.9 | 0.0 | 0.0 |
| *Panel B: Threshold-based Forward Guidance*, π*=2 | | | | | | | |
| Inflation > 2 | 17.4 | 1.6 | 1.0 | 55.6 | 34.6 | 0.0 | 0.0 |
| *Panel C: Quantitative Easing*, π*=2 | | | | | | | |
| QE (D) | 3.4 | 0.2 | 1.9 | 26.4 | 13.5 | 1,260 | 4,073 |
| *Panel D: Forward Guidance + Quantitative Easing*, π*=2 | | | | | | | |
| Inflation > 2 + QE (D) | 3.0 | -0.2 | 2.2 | 28.9 | 17.8 | 972 | 3,353 |