A Model of Post-2008 Monetary Policy

Behzad Diba — Georgetown University
Olivier Loisel — CREST

December 2021

Overview

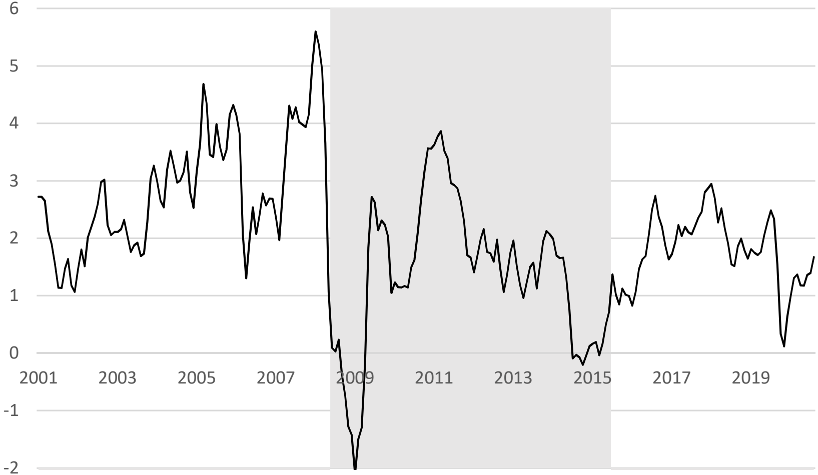
- Since the end of 2008, the Federal Reserve has been communicating its monetary policy in terms of **two instruments**:
  - the interest rate on bank reserves (IOR rate),
  - the size of its balance sheet.
- We propose a **simple model** in which the central bank sets these two instruments.
- Looking **backward**, we show that the model can qualitatively account for key observations about US **inflation** and **money-market rates** during the 2008-2015 zero-lower-bound (ZLB) episode.
- Looking **forward**, we explore the model's implications for the **normalization** and the **operational framework** of monetary policy.

Challenges to Existing Theories

- During the ZLB episode, inflation was **neither very low, nor very volatile, nor very large**.
- Cochrane (2018): "*The long period of quiet inflation at near-zero interest rates, with large quantitative easing, suggests that core monetary doctrines are wrong.*"
  - **New Keynesian** models imply large deflation & inflation volatility at the ZLB.
  - **Monetarist** models imply large inflation following quantitative easing (QE).
- Additional challenge to **monetarist** models: T-Bill rates dropped below the IOR rate during the ZLB episode (and beyond), suggesting money demand was **satiated**.

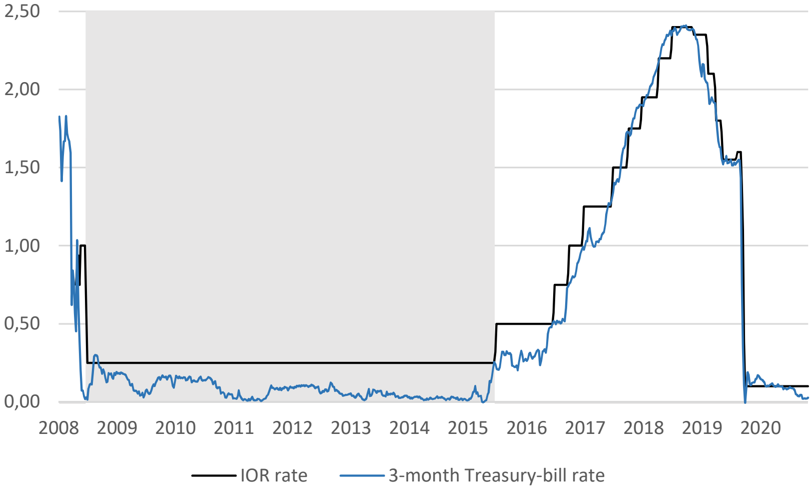
US Inflation, 2001-2021

(year-on-year growth rate in the Consumer Price Index, in percent per year)



US Interest Rates, 2008-2021

(in percent per year)



Looking Backward

- Our model introduces a monetarist element – **bank reserves** – into the basic New Keynesian (NK) model (Woodford, 2003, Galí, 2015).
- This monetarist element implies **no significant deflation** and **little inflation volatility** at the ZLB.
- The model can account for **no significant inflation** following QE if
  - the demand for reserves is close to satiation,
  - the monetary expansion is perceived as temporary.
- An extension of our model (with T-bills providing liquidity services to non-bank financial institutions) can push **T-bill rates below the IOR rate** without requiring satiation of demand for reserves.

Looking Forward

- Our model always implies deflationary effects of **monetary-policy normalization** (current and expected future IOR-rate hikes and balance-sheet contractions).
- In our model, **corridor and floor systems** have different implications for equilibrium determinacy:
  - the condition for **local**-equil. determinacy is weaker under the floor system,
  - however, the floor system may generate **global**-equilibrium indeterminacy.

Related Literature

- **Price-level determination**: Canzoneri and Diba (2005), Hagedorn (2018), Benigno (2020).
- **Quantitative easing**: Cúrdia and Woodford (2011), Gertler and Karadi (2011), Ennis (2018), Sims et al. (2020).
- **NK puzzles and paradoxes**: Carlstrom et al. (2015), Cochrane (2017), Diba and Loisel (2021).
- **Neo-Fisherian effects**: Schmitt-Grohé and Uribe (2017), Bilbiie (2018).
- **Floor vs. corridor systems**: Arce et al. (2019), Piazzesi et al. (2019).

Households

- The representative household consists of **workers** and **bankers**, and their intertemporal **utility function** is

$$U_t = \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \beta^k \zeta_{t+k} \left[u\left(c_{t+k}\right) - v\left(h_{t+k}\right) - v^b\left(h^b_{t+k}\right) \right] \right\}.$$

- Bankers use their own labor h^b_t and real reserves m_t to produce loans:

$$\ell_t = f^b\left(h^b_t, m_t\right).$$

- We can invert f^b and rewrite bankers' labor disutility as $v^b(h^b_t) = \Gamma(\ell_t, m_t)$.

- The first-order conditions imply $I^\ell_t > I_t > I^m_t$ (loans pay more interest than bonds, which pay more interest than reserves).

Firms and Central Bank

- **Firms** are monopolistically competitive and owned by households.
- They use workers' labor to produce output: $y_t = f(h_t)$.
- They have to **borrow a fraction** $\phi \in (0, 1]$ **of their nominal wage bill** $P_t \ell_t = \phi W_t h_t$ in advance from banks, at the gross nominal interest rate I_t^ℓ.
- Prices can be **sticky** à la Calvo (1983), with a degree of price stickiness $\theta \in [0, 1)$.
- The **central bank** has two independent instruments:
    - the (gross) nominal interest rate on reserves $I_t^m \geq 1$,
    - the quantity of nominal reserves $M_t > 0$.

Local Analysis I

- We assume that I_t^m and M_t are set exogenously around $I^m \in [1, \beta^{-1})$ and $M > 0$, and get a **unique steady state** (in which I^m pins down $m \equiv M/P$, and M pins down P).

- We **log-linearize** the model around its unique steady state and get:

$$\begin{aligned} \widehat{y}_t &= \mathbb{E}_t \{\widehat{y}_{t+1}\} - (1/\sigma)(i_t - \mathbb{E}_t \{\pi_{t+1}\} - r_t), \\ \pi_t &= \beta \mathbb{E}_t \{\pi_{t+1}\} + \kappa (\widehat{y}_t - \delta_m \widehat{m}_t), \\ \widehat{m}_t &= \chi_y \widehat{y}_t - \chi_i (i_t - i_t^m). \end{aligned}$$

- These equations lead to a **dynamic equation** for the price level $\widehat{P}_t$ of type

$$A_2 \mathbb{E}_t \{\widehat{P}_{t+2}\} + A_1 \mathbb{E}_t \{\widehat{P}_{t+1}\} + A_0 \widehat{P}_t + A_{-1} \widehat{P}_{t-1} = Z_t,$$

  where Z_t is exogenous (function of r_t, i_t^m, and $\widehat{M}_t$).

- We show that the roots of the characteristic polynomial are always three real numbers ρ, ω_1, and ω_2 such that $0 < \rho < 1 < \omega_1 < \omega_2$.

Local Analysis II

- So, we always get local-equilibrium **determinacy**.

- The model makes inflation depend on expected future shocks in a way that decreases (exponentially) with the horizon of shocks:

$$\pi_t = -(1-\rho)\,\widehat{P}_{t-1} + \frac{\mathbb{E}_t}{\omega_2 - \omega_1}\left\{\sum_{k=0}^{+\infty} \underbrace{\left(\omega_1^{-k-1} - \omega_2^{-k-1}\right)}_{\text{decreases with } k} Z_{t+k}\right\}.$$

- In particular, for a **temporary ZLB episode** caused by a negative discount-factor shock ($i_t^m - r_t = z^* > 0$ for $0 \leq t \leq T$), we have

$$\pi_0 = -(1-\rho)\,\widehat{P}_{t-1} + \frac{-\kappa z^*}{\beta\sigma\,(\omega_2 - \omega_1)} \sum_{k=0}^{T} \underbrace{\left(\omega_1^{-k-1} - \omega_2^{-k-1}\right)}_{\textbf{decreases with } k}.$$

Local Analysis III

- By contrast, the basic NK model generates local-equilibrium **indeterminacy** under an exogenous interest rate; and, for the same **temporary ZLB episode**, we have

$$\pi_0 = \frac{-\kappa z^*}{\beta\sigma\left(\omega_b - \rho_b\right)} \sum_{k=0}^{T} \underbrace{\left(\rho_b^{-k-1} - \omega_b^{-k-1}\right)}_{\text{increases with } k},$$

where $\rho_b \in (0,1)$ and $\omega_b > 1$ denote the roots of the characteristic polynomial.

- So, relatively to the basic NK model, our model will typically imply
  - a **much smaller deflation** (i.e. $|\pi_0|$ much smaller),
  - a **much less volatile inflation** (in response to expected future shocks).

- We show that these results are essentially **robust** to
  - the endogenization of nominal reserves,
  - the introduction of household cash.

Global Analysis: Steady State

- We assume **flexible prices** ($\theta = 0$), no discount-factor shocks ($\zeta_t = 1$), and
  - a constant growth rate of reserves: $\mu_t \equiv M_t / M_{t-1} = \mu > 0$,
  - a constant IOR rate: $I_t^m \in [1, \mu/\beta)$.
- We get a **dynamic equation** of type $1 + \mathcal{F}(h_t) = (\beta I^m / \mu) \mathbb{E}_t \{\mathcal{G}(h_{t+1}) / \mathcal{G}(h_t)\}$.
- We get a **unique constant-inflation equilibrium** (in which gross inflation Π_t equals μ). At this unique steady state, I^m and μ pin down m, and M_t pins down P_t.
- So, our monetarist model has **no "unintended" deflationary ZLB steady state** à la Benhabib et al. (2001a, 2001b).
- **At the ZLB** ($I^m = 1$), the model rules out steady-state deflation **provided that** $\boldsymbol{\mu \geq 1}$.

Global Analysis: Dynamic Equilibria

- We also get **dynamic equilibria with below-steady-state inflation** ($\Pi_t < \mu$) if and only if $I^m > \mu$.
- In these equilibria,
  - the economy converges over time to satiation of demand for reserves,
  - so, the real return on reserves, I^m/Π_t, converges over time to $1/\beta$,
  - so, gross inflation Π_t converges over time to βI^m,
  - so, the asymptotic gross growth rate of real reserves is $\mu/(\beta I^m)$,
  - so, the transversality condition is satisfied if and only if $I^m > \mu$.
- **At the ZLB** ($I^m = 1$), the model rules out dynamic equilibria with below-steady-state inflation **provided that $\mu \geq 1$** (as in Obstfeld and Rogoff, 1983, Benhabib et al., 2002).

Numerical Simulation of QE2 I

- We conduct a **non-linear numerical simulation** of (one to four times) QE2 in our model with sticky prices.

- To that aim,
  - we consider iso-elastic functional forms for the production and utility functions,
  - we calibrate the model to match some features of the US economy in 2010.

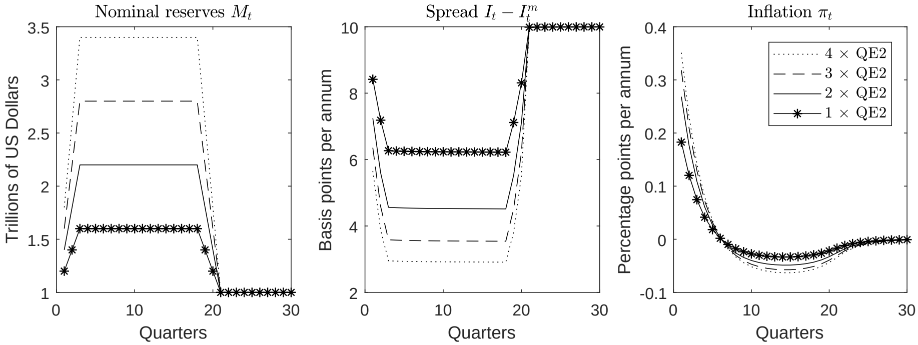
- We get **very small inflationary effects** under two conditions:
  - demand for reserves is close to satiation (i.e. I^m is close to $I = \mu/\beta$),
  - the monetary expansion is perceived as temporary.

- When I^m is close to I, Γ_m is close to 0, and the reserves-market-clearing condition

$$\Gamma_m\left(\ell_t, \frac{M_t}{P_t}\right) = -\left(\frac{I_t - I_t^m}{I_t}\right) u'(c_t)$$

implies that **a large increase in M_t can be absorbed by a small drop in $I_t - I_t^m$** without changing P_t by much.

Numerical Simulation of QE2 II



- In the benchmark calibration used above, the steady-state spread $I - I^m$ is **10 basis points**, and the expected duration of the monetary expansion is **5 years**.
- The increase in annualized inflation would **roughly double** if the steady-state spread $I - I^m$ were **20 basis points**, or if the expected duration of the monetary expansion were **10 years**.

Extension With Liquid Government Bonds I

- One argument against our **non-satiation assumption** is that T-bill rates dropped below the IOR rate during the ZLB episode.

- To reconcile our model with this observation, we introduce **government bonds providing liquidity services** to
  - banks (which have access to the IOR rate),
  - other financial institutions (which don't).

- We assume that workers get utility from holding government bonds (b_t^w), and that bankers may use reserves (m_t) and government bonds (b_t^b) to produce loans (ℓ_t):

$$U_t = \mathbb{E}_t \left\{ \sum_{k=0}^{\infty} \beta^k \zeta_{t+k} \left[u\left(c_{t+k}\right) - v\left(h_{t+k}\right) - \Gamma\left(\ell_{t+k}, m_{t+k} + \eta b_{t+k}^b\right) + z\left(b_{t+k}^w\right) \right] \right\},$$

where $\eta \in (0, 1]$.

Extension With Liquid Government Bonds II

- We show that our model *with* liquid bonds has an equilibrium
  - in which the IOR rate is above the government-bond yield ($I_t^m > I_t^b$),
  - in which banks hold only reserves for liquidity management ($b_t^b = 0$),
  - which coincides with the equilibrium of our model *without* liquid bonds.

- So, our extended model
  - **accounts for the negative spread** between T-bill and IOR rates at the ZLB,
  - **preserves the implications** of our benchmark model for inflation at the ZLB.

Normalization of Monetary Policy

- In our model, current and expected future IOR-rate hikes and balance-sheet contractions are **always deflationary**:

$$\pi_t = -(1-\rho)\widehat{P}_{t-1} + \frac{(1-\delta_m\chi_y)\kappa}{\beta\sigma\chi_i(\omega_1-1)(\omega_2-1)}\widehat{M}_{t-1}$$
$$+ \underbrace{\frac{\kappa}{\beta(\omega_2-\omega_1)}}_{>0}\mathbb{E}_t\left\{\sum_{k=0}^{+\infty}\underbrace{\left[\frac{-1}{\sigma}\left(\omega_1^{-k-1}-\omega_2^{-k-1}\right)\right]}_{<0}\left(i_{t+k}^m - r_{t+k}\right)\right.$$
$$\left.+\sum_{k=0}^{+\infty}\underbrace{\left[\left(\frac{1-\delta_m\chi_y}{\sigma\chi_i}\right)\left(\frac{\omega_1^{-k}}{\omega_1-1}-\frac{\omega_2^{-k}}{\omega_2-1}\right)+\delta_m\left(\omega_1^{-k}-\omega_2^{-k}\right)\right]}_{>0}\widehat{\mu}_{t+k}\right\}.$$

- So, in particular, our model implies **no Neo-Fisherian effects**.

Operational Framework: Local Analysis

- We consider in turn a **corridor system** and a **floor system**, both with a log-linearized rule of type $i_t^m = \psi \pi_t$ with $\psi \geq 0$.

- Under the **corridor system**, we have $i_t - i_t^m = 0$, so the reserves-market-clearing condition becomes $\widehat{m}_t = \chi_y \widehat{y}_t$, the Phillips curve can be rewritten as

$$\pi_t = \beta \mathbb{E}_t \{\pi_{t+1}\} + \kappa \underbrace{(1 - \delta_m \chi_y)}_{>0} \widehat{y}_t,$$

  and the model is isomorphic to the basic NK model. The implied rule for i_t is $i_t = \psi \pi_t$, and we need $\psi > 1$ to get local-equilibrium determinacy (**Taylor principle**).

- Under the **floor system**, we already know that $\psi = 0$ delivers local-equilibrium determinacy. We show that, more generally, any $\psi \geq 0$ ensures local-equilibrium determinacy (**no Taylor principle**).

Operational Framework: Global Analysis I

- However, the **floor system** may generate **global**-equilibrium indeterminacy when $0 \leq \psi < 1$, at least under flexible prices.

- For $\psi = 0$, when $I_t^m = I^m$ and $\mu_t = \mu$, we get (an infinity of) **dynamic equilibria with $\Pi_t < \mu$** if and only if $I^m > \mu$:
  - under **scarce reserves** ($I^m \leq \mu$), no such equilibrium exists, and $\Pi_t = \mu$,
  - under **ample reserves** ($I^m > \mu$), these equilibria exist, and $\Pi_t \leq \mu$,
  - under **very ample reserves** ($I^m \to \mu/\beta$), these equilibria exist, but $\Pi_t \to \mu$ in any of these equilibria at any date t (so that $I^m/\Pi_t \to 1/\beta$).

- So, in order to stabilize inflation Π_t at a given target μ or close to it, the floor system should involve **either scarce or very ample reserves** when $\psi = 0$.

Operational Framework: Global Analysis II

- More generally, for $\psi \geq 0$, when $I_t^m = \max\left[I^m (\Pi_t/\mu)^\psi, 1\right]$ and $\mu_t = \mu$, we get a unique equilibrium (and $\Pi_t = \mu$ in this equilibrium) if and only if

$$\mu \geq \max(\underset{\substack{\uparrow \\ \text{to avoid eq. with below-SS} \\ \text{inflation and binding ZLB}}}{1}, \quad \underset{\substack{\uparrow \\ \text{to get} \\ \text{a SS eq.}}}{\beta I^m}, \quad \underset{\substack{\uparrow \\ \text{to avoid eq. with below-SS} \\ \text{inflation and non-binding ZLB}}}{\beta^\psi I^m}).$$

- So, for $0 \leq \psi < 1$,
  - $\Pi_t = \mu$ under **scarce reserves** ($I^m \leq \mu/\beta^\psi$),
  - $\Pi_t \leq \mu$ under **ample reserves** ($I^m > \mu/\beta^\psi$),
  - $\Pi_t = \mu$ or $\Pi_t \to \mu$ under **very ample reserves** ($I^m \to \mu/\beta$),

  as previously with $\psi = 0$.

- So, again, the floor system should involve **either scarce or very ample reserves**.

Summary

- In this paper, we propose a model in which the central bank sets **two instruments**:
  - the interest rate on bank reserves,
  - the size of its balance sheet.
- Looking **backward**, we show that the model can qualitatively account for key observations about US **inflation** and **money-market rates** during the 2008-2015 ZLB episode.
- Looking **forward**, we explore the **implications** of our model for
  - the normalization of monetary policy,
  - its operational framework (floor vs. corridor system).

Robustness Check #1: Endogenous Nominal Reserves

- In our benchmark model, the stock of nominal reserves is **exogenous**.
- We endogenize it by considering the rule $M_t = P_t \mathcal{R}(P_t, y_t)$, with $\mathcal{R}_P < 0$ and $\mathcal{R}_y \leq 0$.
- The steady state is still unique, and we derive a simple sufficient **condition for local-equilibrium determinacy** under an exogenous IOR rate.
- We argue that **this condition is met** except for implausible calibrations.
- The shadow rule for i_t is still **Wicksellian**:

$$i_t \underset{\uparrow}{=} i_t^m + \frac{\chi_y}{\chi_i}\widehat{y}_t - \frac{1}{\chi_i}\widehat{m}_t \underset{\uparrow}{=} i_t^m + \frac{\chi_y}{\chi_i}\widehat{y}_t - \frac{1}{\chi_i}\left(-r_P \widehat{P}_t - r_y \widehat{y}_t\right).$$

reserves-market-clearing condition   nominal-reserves rule

Robustness Check #2: Household Cash

- In our benchmark model, the central bank controls **bank reserves**; but in reality, it controls the **monetary base** (bank reserves and cash).
- We introduce **household cash**, through a cash-in-advance (CIA) constraint, into our benchmark model.
- Again, the steady state is still unique, and we derive a simple sufficient **condition for local-equilibrium determinacy** under an exogenous IOR rate.
- Again, we argue that **this condition is met** except for implausible calibrations.
- Again, the shadow rule for i_t is still **Wicksellian**:

$$i_t \underset{\uparrow}{=} i_t^m + \frac{\chi_y}{\chi_i}\widehat{y}_t - \frac{1}{\chi_i}\widehat{m}_t \underset{\uparrow}{=} i_t^m + \frac{\chi_y}{\chi_i}\widehat{y}_t - \frac{1}{\chi_i}\left[\frac{1}{1-\alpha_c}\left(\widehat{M}_t - \widehat{P}_t\right) - \frac{\alpha_c}{1-\alpha_c}\widehat{y}_t\right].$$

reserves-market-clearing condition

money-market-clearing condition and binding CIA constraint