

A Model of Post-2008 Monetary Policy

Behzad Diba
Georgetown University

Olivier Loisel
CREST

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Overview

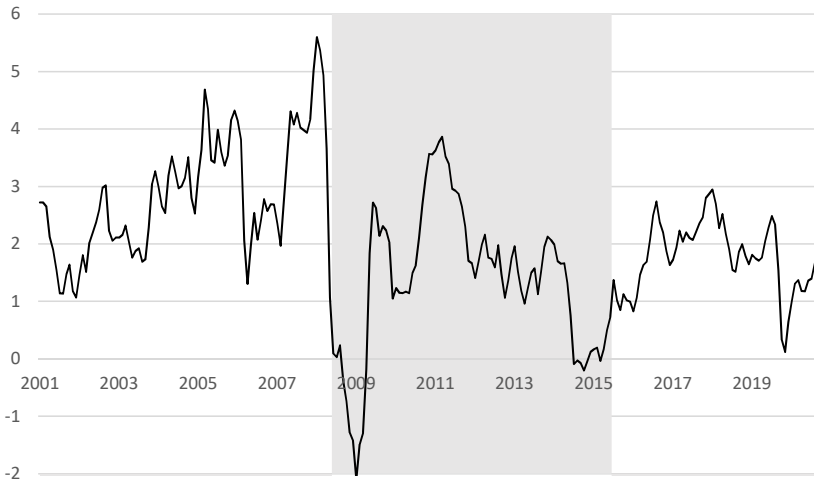
- Since the end of 2008, the Federal Reserve has been communicating its monetary policy in terms of **two instruments**:
 - the interest rate on bank reserves (IOR rate),
 - the size of its balance sheet.
- We propose a **simple model** in which the central bank sets these two instruments.
- Looking **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**.

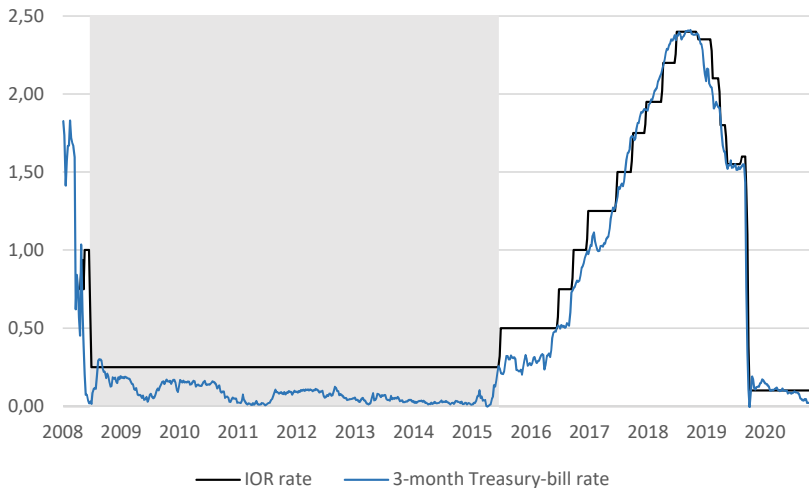
US Inflation, 2001-2021

(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

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

- Bankers use their own labor h_t^b and real reserves m_t to produce loans:

$$\ell_t = f^b(h_t^b, m_t).$$

- We can invert f^b and rewrite bankers' labor disutility as $v^b(h_t^b) = \Gamma(\ell_t, m_t)$.
- The first-order conditions imply $I_t^\ell > I_t > I_t^m$ (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:

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

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

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

where Z_t is exogenous (function of r_t , i_t^m , and \hat{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:

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

- 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

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

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

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

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** $\mu \geq 1$.

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).

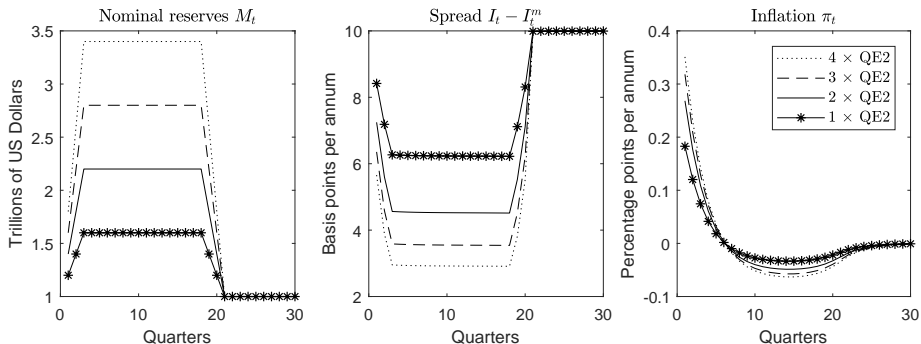
Numerical Simulation of QE2 I

- 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):

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

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**:

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

- 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 $\hat{m}_t = \chi_y \hat{y}_t$, the Phillips curve can be rewritten as

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

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** ($I^m \rightarrow \mu/\beta$), these equilibria exist, but $\Pi_t \rightarrow \mu$ in any of these equilibria at any date t (so that $I^m/\Pi_t \rightarrow 1/\beta$).
- 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

$$\mu \geq \max(1, \quad \beta I^m, \quad \beta^\psi I^m).$$

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 to avoid eq. with below-SS to get to avoid eq. with below-SS
 inflation and binding ZLB a SS eq. inflation and non-binding ZLB

- 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 $\Pi_t \rightarrow \mu$ under **very ample reserves** ($I^m \rightarrow \mu / \beta$),
 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**:

$$\underset{\substack{\uparrow \\ \text{reserves-market-clearing condition}}}{i_t} = \underset{\substack{\uparrow \\ \text{nominal-reserves rule}}}{i_t^m} + \frac{\chi_y}{\chi_i} \hat{y}_t - \frac{1}{\chi_i} \hat{m}_t = \underset{\substack{\uparrow \\ \text{nominal-reserves rule}}}{i_t^m} + \frac{\chi_y}{\chi_i} \hat{y}_t - \frac{1}{\chi_i} \left(-r_P \hat{P}_t - r_y \hat{y}_t \right).$$

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**:

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

reserves-market-clearing condition

money-market-clearing condition
and binding CIA constraint