The views expressed here are those of the authors and do not necessarily represent those of the IMF, its Executive Board, IMF management, the Federal Reserve Bank of San Francisco, or the Board of Governors of the Federal Reserve System.
Consensus that QE reduced long-term interest rates

But the transmission to long rates is not well understood, conceptually and empirically

Notably, lack of theoretical accounting for role of central bank reserves and commercial banks

Transmission details matter for how to best design, calibrate, communicate, and exit QE programs
Our Contribution

- We present a portfolio model with a CB, reserve-holding banks, and non-bank financial institutions.

- Two financial frictions, imperfect substitutability and segmentation of the market for central bank reserves, lead to two distinct portfolio balance effects:
  - Standard supply induced effects due to a lower available supply of the purchased assets, and
  - Reserve induced portfolio effects, independent of the specific assets purchased.

- Application: Impact of leverage constraints on QE transmission.
Outline

1. Non-technical Overview
2. The Model
3. Empirical Relevance
4. Conclusions and Implications
Previous PB models of QE one-sided:
- Seminal paper: Vayanos Vila 2009
- No role for reserves or banks
- CB bond purchases modelled as exogenous reduction in supply
- Price re-equilibrates demand and supply

What about the other side of the QE transaction? CB reserves
- Bernanke and Reinhart (2004) argue that an expansion of reserves by itself can have PB effects
- ...but do not present a model of the mechanism.
We Include Reserves and Banks in a PB Model

Portfolio model of a financial market:

- **Three actors**: CB, banks and non-bank financial firms
- **Four assets**: long bonds, short bonds, bank deposits and central bank reserves
- **Two central frictions** (more can be added):
  - Only banks can hold reserves, and
  - Imperfect asset substitutability
- **Central assumption**:
  - Banks’ bond demand propensity out of new funding is positive, given asset prices
Example: CB purchases short bonds from banks (green)
Standard macro: short bonds and money perfect substitutes at ZLB, no effect
Now consider purchases from non-banks (black arrows)
Initial impact: Bank balance sheets extend, their demand for non-reserve assets increases.

The extra reserves must stay in banks: Hot potato effect....

... until longer-duration yields decline enough to make banks content to hold the extra reserves.
Reserve-induced effects arise when assets are purchased from non-banks, and are independent of the assets.

Long bonds can have both reserve and supply effects.
Outline

1. Non-technical Overview
2. The Model
3. Empirical Relevance
4. Conclusions and Implications
Modelling Approach and Versions

- One period model of asset market equilibrium with smallest number of features to illustrate that reserves matter

- Long-term bond demand assumptions:
  - Imperfect substitutability: $-\infty < \frac{\partial f_j}{\partial P_L} < 0$
  - Banks’ bond demand propensity out of new funding: $0 < \frac{\partial f_B}{\partial D_B} < 1$

- Different model versions:
  - Benchmark model with one traded security (the long bond, L): simple, tractable, captures all effects
  - Two traded securities version (long and short bonds): confirms findings of one-security version
The equilibrium bond price ensures aggregate demand for bonds in banks and non-banks equals total supply of bonds net of central bank holdings.

Comparative statics. Change in equilibrium bond price associated with a QE transaction:

$$\frac{dP_L}{dL_{CB}} = \frac{-1}{\frac{\partial f_{NB}}{\partial P_L} + \frac{\partial f_B}{\partial P_L} - P_L \frac{\partial f_{NB}}{\partial P_L} \frac{\partial f_B}{\partial D_B}}$$

First two terms in denominator are supply induced effects. Third term is reserve induced effect.

Price impact depends on price sensitivity of bond demand, and banks’ bond demand propensity from new funding.
To identify reserve effects, we need QE-style CB reserve expansions without long-term bond purchases.

The Swiss reserve expansion program of August 2011:
- Akin to natural experiment of QE in short-term bonds
- Christensen and Krogstrup (FRBSF WP 2016) find support for reserve induced effects

Event studies of US and UK QE cannot identify, but:
- Exit may provide insights: Bonds roll off - reserves effect?
- Studies indicate non-bank counterparties and bank balance sheet expansions associated with parts of QE (Joyce et al. 2011, Ennis and Wollman 2015, Carpenter et al. 2013)
Empirical Relevance of Reserve-Induced Effects

Data on bank total liabilities suggest the conditions were there for reserve induced effects during QE2 and QE3:

- Fed asset purchases
- US bank liabilities net of interbank loans
1. Non-technical Overview
2. The Model
3. Empirical Relevance
4. Conclusions and Implications
We develop a portfolio model of QE transmission to asset prices that includes central bank reserves and banks

**Main finding**: PB effects come in two variants
- Supply induced PB effect
- Reserve induced PB effects

**The distinction matters**. Reserve effects are different:
- Independent of the assets that central bank is purchasing
- Depend on features of market and banking system (preferences and constraints)

**Empirically relevant**. Effects shown for Swiss reserve expansions. Likely to have played a role BoE and Fed QE
Implications for the design and transmission of QE programs:

- **Which assets to buy?** Not necessary to buy long-dated securities to affect long-term yields
- **Financial institutional structure matters.** Who has access to reserves, and preferred habitat investors
- **Role of bank regulation** in transmission: bank leverage constraints and portfolio risk management models of non-banks matter
- **Transmission and Exit:** Rolling off of bonds akin to sales of short bonds. Reverse reserve effects?
Thank you!
Model With One Traded Security

One period model of asset market equilibrium

- Three types of actors:
  - A central bank (CB)
  - An infinity of reserve holding commercial banks (B)
  - An infinity of non-bank financial firms (NB)

- Three types of assets (simplest case):
  - Long bonds, $L$, with the price of $P_L$ and $TP = 1 - P_L$
  - Central bank reserves, $R$, with the price of one (numeraire)
  - Bank deposits, $D$ with the price of one
The Model (2)

The central bank balance sheet:

\[ \begin{align*}
P_L L_{CB} &= E_{\text{CB}} + R \\
L_{CB}: \text{is the central bank’s holdings } L \\
E_{\text{CB}}: \text{is the value of the central bank’s initial equity} \\
R: \text{is outstanding reserves}
\end{align*} \]

Policy tool is bond purchases, \( P_L dL_{CB} \), paid for by reserves, \( dR \), and equity is residually determined by bond price changes:

\[ dE_{\text{CB}} = dP_L L_{CB} + P_L dL_{CB} - dR \]
The non-bank financial firm $j$ balance sheet:

\[ P_L L^j_{NB} + D^j_{NB} = E^j_{NB} \]

- $L^j_{NB}$ is firm $j$'s holdings of bonds
- $D^j_{NB}$ holdings of bank deposits
- $E^j_{NB}$ initial equity value

Non-banks obtain deposits by selling bonds and vise versa, equity is residually determined by price changes:

\[ dE^j_{NB} = dP_L L^j_{NB} + P_L dL^j_{NB} + dD^j_{NB} \]
Non-bank financial firms balance their liquid portfolio between deposits and bonds, demanding positive amounts of both:

\[ L_{NB}^j = f_{NB}(P_L, E_{NB}^j) \]

\[ \frac{\partial f_{NB}}{\partial P_L} < 0 \text{ Normal downward sloping demand Substitutability} \]

\[ \frac{\partial f_{NB}}{\partial E_{NB}} = 0 \text{ No real-time reaction to changes in equity value. Allows more tractability, not central for results} \]

The demand for deposits is determined as a residual:

\[ D_{NB}^j = E_{NB}^j - P_L f_{NB}(P_L, E_{NB}^j) \]
Depository bank $i$ balance sheet:

$$R^i + P_LL^i_B = E^i_B + D^i_B$$

- $L^i_B$ is bank $i$'s holdings of bonds
- $R^i$ is its holdings of central bank reserves
- $D^i_B$ is the bank’s deposit funding
- $E^i_B$ initial equity value

Banks can obtain reserves by selling bonds. Reserves fluctuate autonomously when bank customers trade bonds for deposits:

$$dR^i = dD^i_B - P_LdL^i_B$$

Bank equity is residually determined by bond-price changes:

$$dE^i_B = dP_LL^i_B$$
The Model (6)

Depository banks’ demand for bonds and reserves:

\[ L^i_B = f_B(P_L, E^i_B + D^i_B) \]

Central assumptions:

- \( \frac{\partial f_B}{\partial P_L} < 0 \) Normal good, imperfect substitutability
- \( 0 < \frac{\partial f_B}{\partial D^i_B} < 1 \) Bank "maturity transformation" assumption

The demand for reserves is determined as a residual:

\[ R^i_B = E^i_B + D^i_B - P_L f_B(P_L, E^i_B + D^i_B) \]
Model Equilibrium

- Assume no market power of individual financial institutions: Continuum of identical banks and nonbanks, normalized to 1: Drop equation subscripts

- The equilibrium bond price ensures aggregate demand for bonds in banks and non-banks equals total supply of bonds net of central bank holdings

- Comparative statics: We analyze the change in equilibrium bond price associated with a QE transaction:

\[-dL_{CB} = dL_B + dL_{NB}\]