Scarce, Abundant, or Ample? A Time-Varying Model of the Reserve Demand Curve

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Brussels, 16 March 2023

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The Reserve Demand Curve

- Reserve demand curve:
  - ◇ price at which banks are willing to trade reserves with each other
  - ◇ as a function of aggregate reserves in the banking system

1. FOMC communicates stance via range for reserves' lending rates

2. Fed can change aggregate reserves, but other factors can too

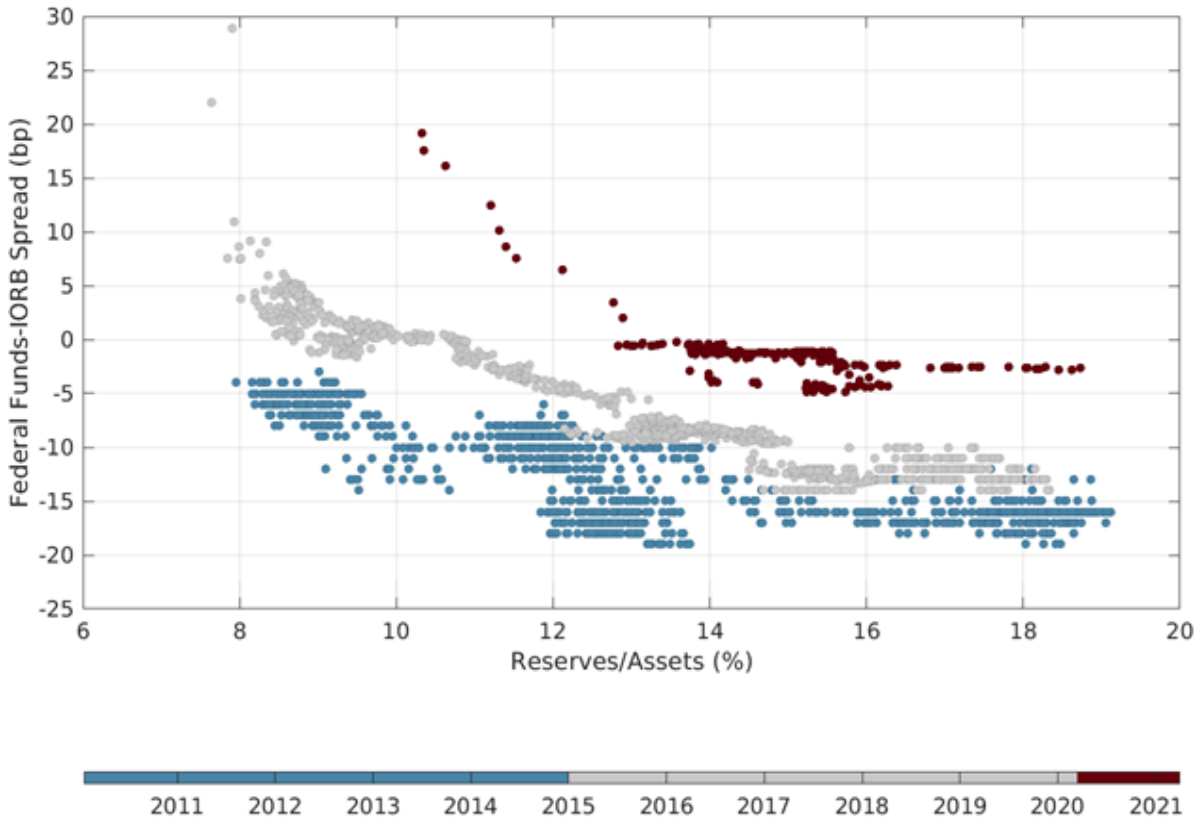
- Question: a well-identified, real-time estimate of its slope?

The FOMC's Ample Reserves Regime

- *"[T]he Committee reaffirms its intention to implement monetary policy in a regime in which an ample supply of reserves ensures that control over the level of the federal funds rate and other short-term interest rates is exercised primarily through the setting of the Federal Reserve's administered rates, and in which active management of the supply of reserves is not required."* (FOMC, October 2019)

- *"Over time, the Committee intends to maintain securities holdings in amounts needed to implement monetary policy efficiently and effectively in its ample reserves regime."* (FOMC, January 2022)

Demand for Reserves: Data



- Goal of this paper: measure the ampleness of the supply of reserves

This Paper Estimates Reserve Demand Curve in 2010-2021

- Three main challenges:
  - ◇ nonlinear relationship between prices and quantities
  - ◇ unobserved structural changes $\Rightarrow$ low-frequency movements
  - ◇ endogeneity of reserves supply

- Our approach:

  time-varying structural (IV) estimation of price sensitivity with daily data

Key Results

- Time-varying estimates of demand elasticity:
  - ◇ Large elasticity $\rightarrow$ "scarce" reserves (2010, 2019)
  - ◇ Near-zero elasticity $\rightarrow$ "abundant" reserves (2012-2017, 2020-now)
  - ◇ Intermediate elasticity $\rightarrow$ "ample" reserves (2011, 2018)
- Ample-to-abundant transition: reserves $\sim$ 12-13% of bank assets
- Demand curve has shifted to the right and upward over time

Outline

1. **Institutional background**

2. Model & Identification Strategy

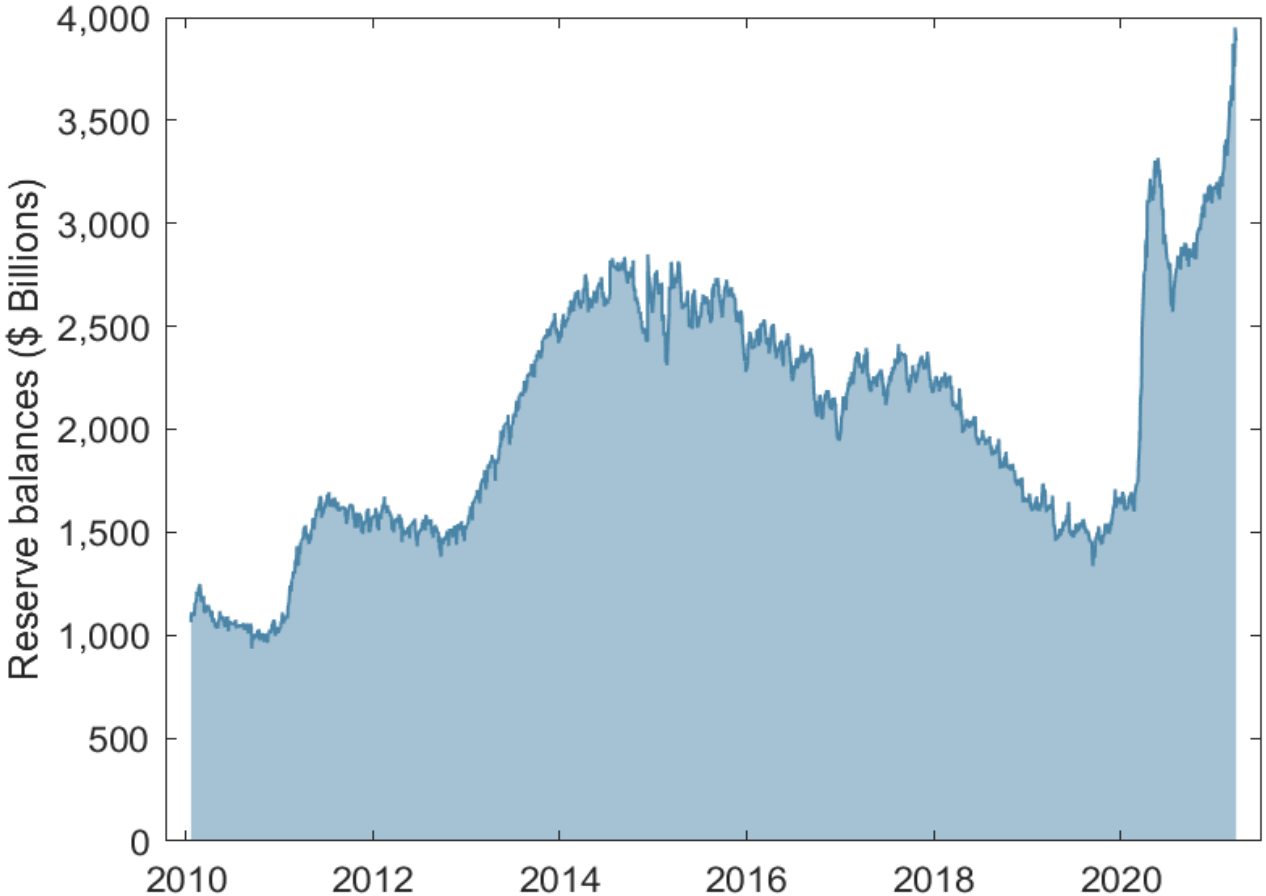
3. OOS Forecast Evaluation (if time permits)

4. Results

Reserves in the U.S. Banking System, 2010-21

Long Sample ▷

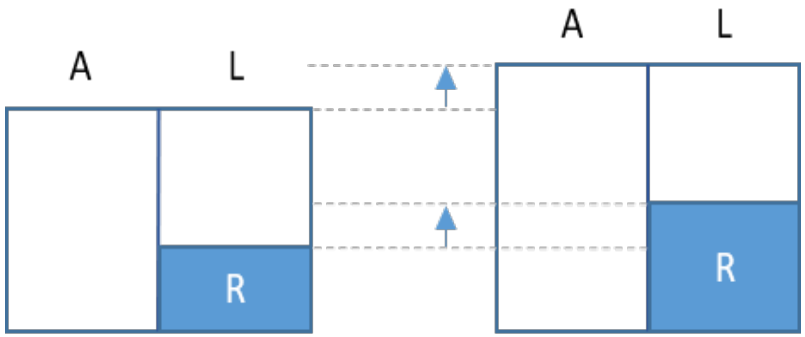
- Reserves: deposits held by banks at the Fed



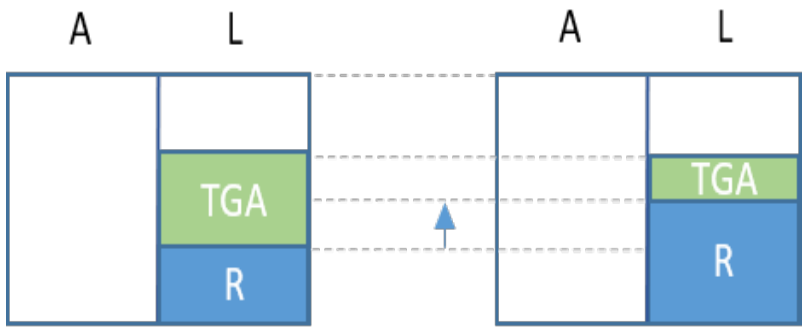
- Billions before 2008 (GFC) → trillions after 2008

How Do Reserves Change? Two Ways

- Reserves: assets for the banks, liability for the Fed



Size of Fed's balance sheet changes



Composition of Fed's liabilities changes

- Left: Fed expands balance sheet $\rightarrow$ reserves increase

- Right: another Fed's liability decreases $\rightarrow$ reserves increase

Non-Reserve Liabilities

- Reserves are not a closed system:
  - ◇ banks transact with holders of non-reserve Fed liabilities

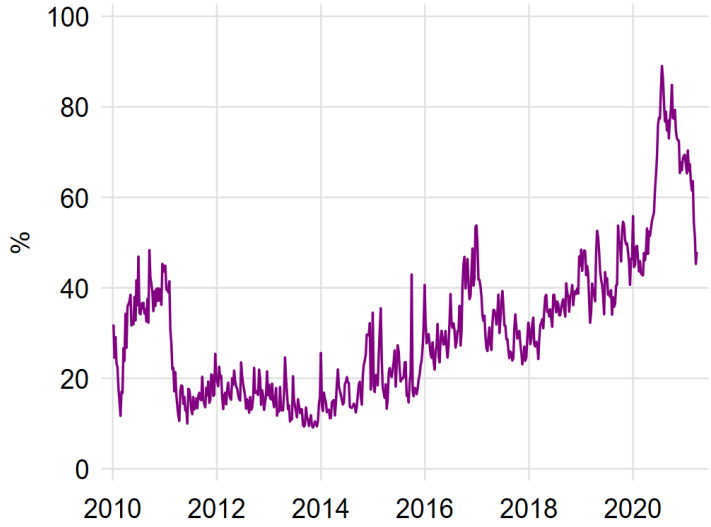
Two important examples:

1. Treasury General Account (TGA)

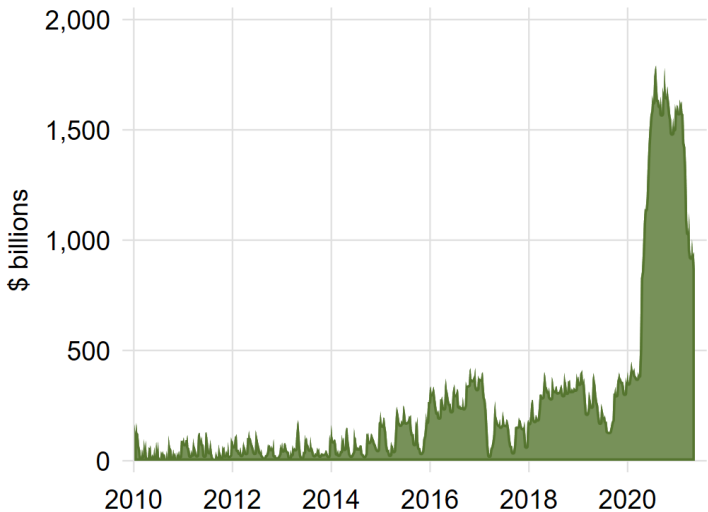
2. Overnight Reverse Repo Facility (ONRRP)

The Growth of Non-Reserve Liabilities

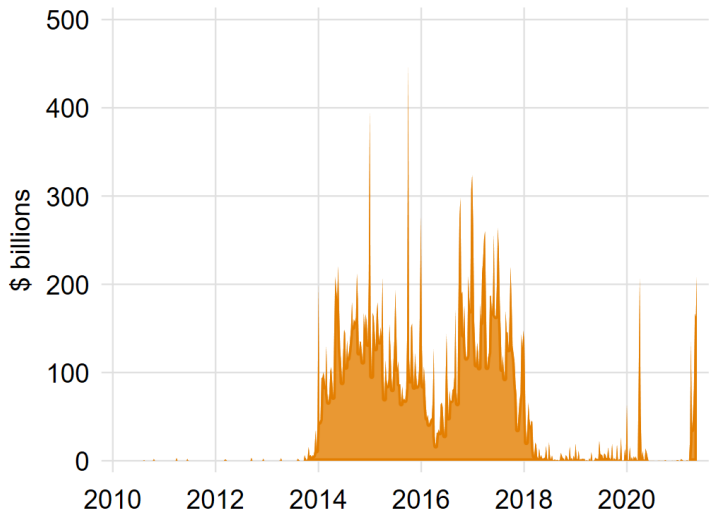
Up to Oct 2022 ▷



Non-Reserves/Reserves



TGA

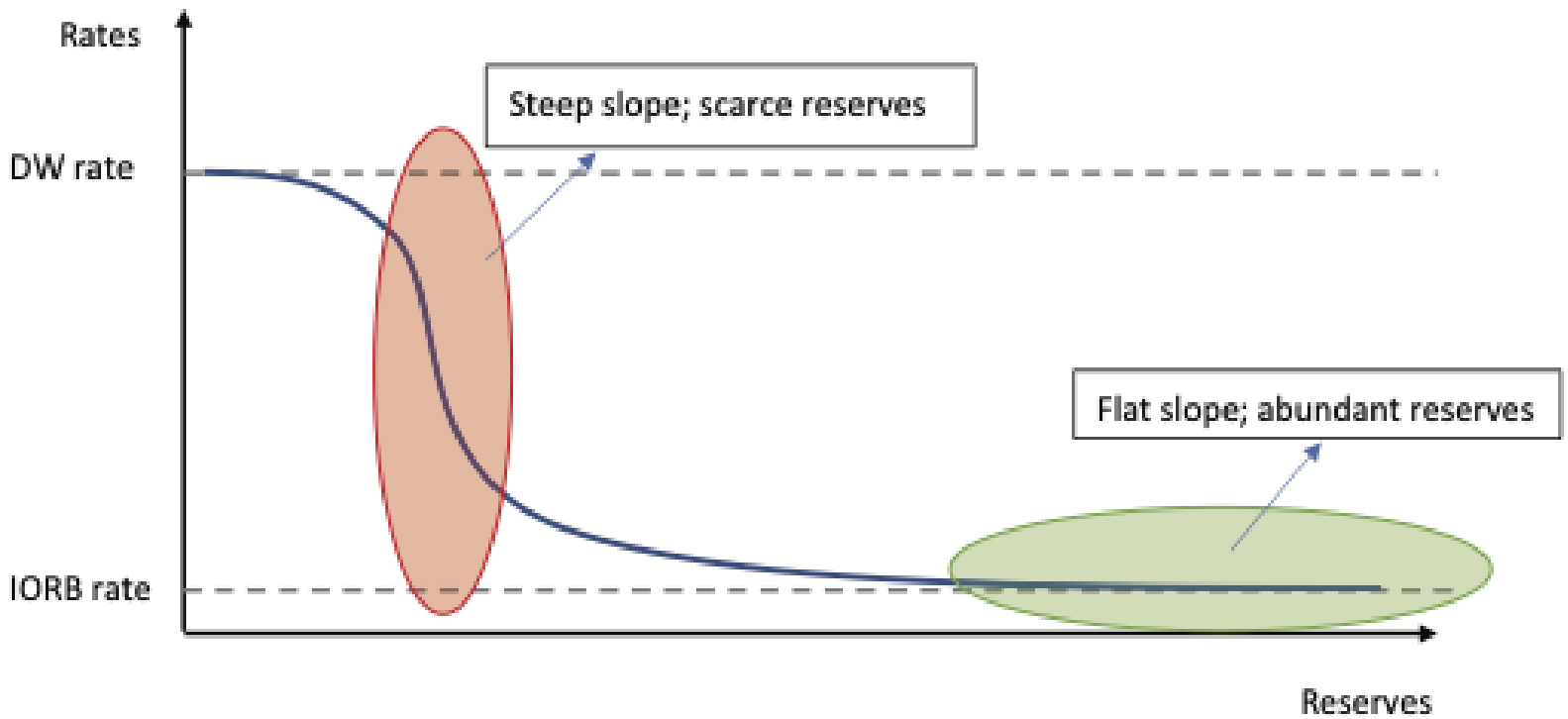


ONRRP

The Federal Funds Market

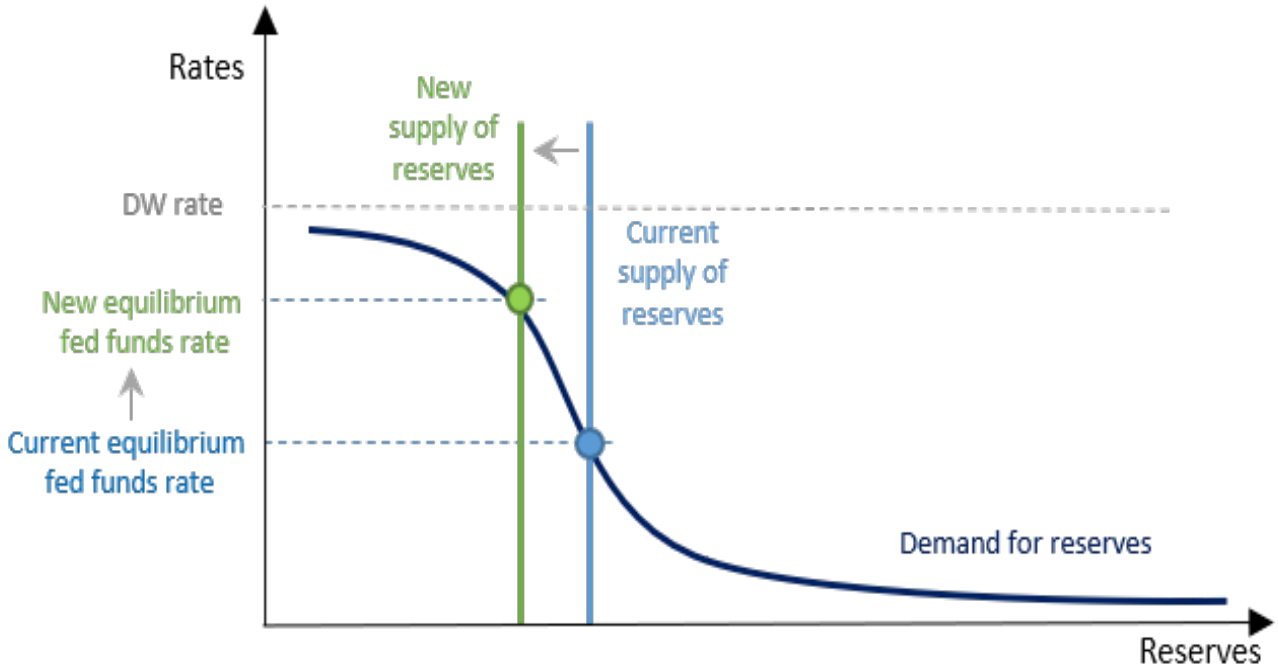
- "Banks" trade reserves in the federal funds market
  - ◇ unsecured lending (mainly overnight)
- Absent frictions, the federal funds rate should be:
  - ◇ above interest on reserve balances (IORB)
  - ◇ below discount window (DW) rate

Reserve Demand Curve: Theory



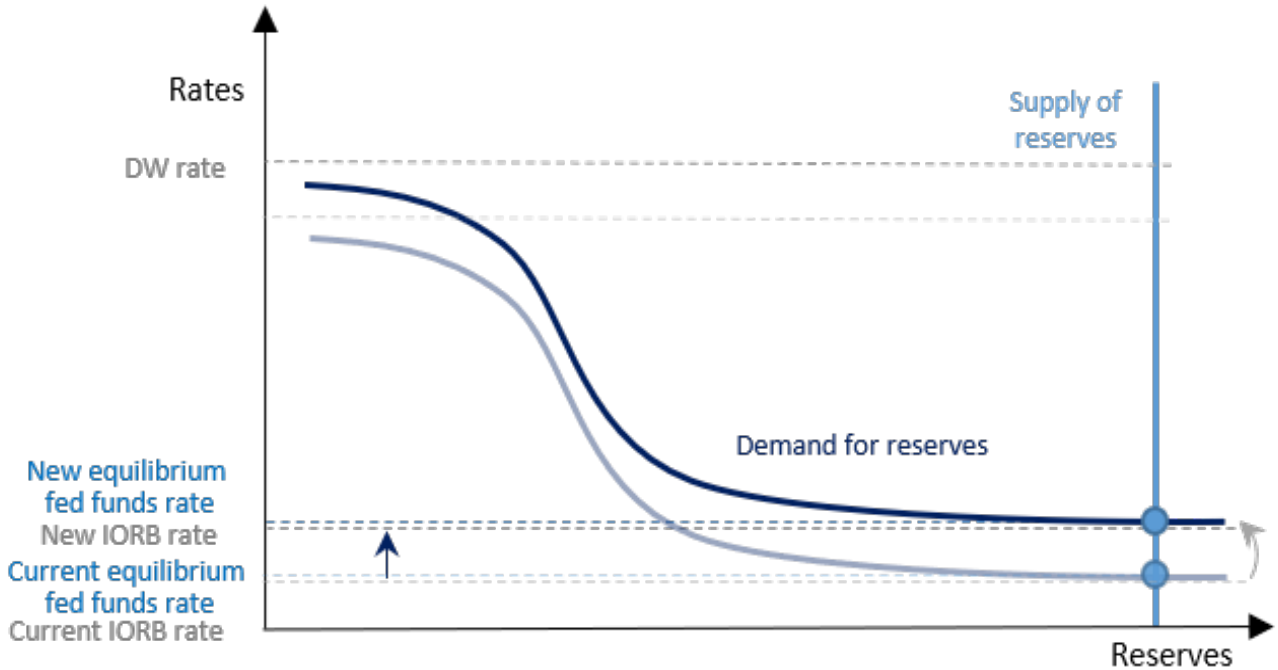
- Between "scarce" and "abundant" $\rightarrow$ "ample" reserves

Monetary Policy Pre 2008



- Reserves: billions & not remunerated (IORB $= 0$) $\Rightarrow$ steep curve
- Fed hits target rate by adjusting reserve supply

Monetary Policy Post 2008



- Reserves: trillions & IORB $> 0 \Rightarrow$ flat curve
- Fed changes IORB (and DW) rate to hit target range

Two Important Frictions

1. Market segmentation: main money-market lenders do not earn IORB
   - ◇ Federal Home Lending Banks (FHLB): federal funds;
   - ◇ Money Market Funds (MMF): Eurodollar, repos

2. Banks' balance-sheet constraints:
   - ◇ Banks are unwilling to borrow if rate is not sufficiently lower than IORB

$\Rightarrow$ EFFR can print below IORB

- 2013: Fed introduced ON RRP for FHLBs & MMFs $\rightarrow$ floor on rates

ONRRP▷

Low-Frequency Drivers of Reserve Demand Post 2008

- Liquidity regulation and internal liquidity-risk management
  - ◇ Examples: Liquidity Coverage Ratio (LCR), thin late-day funding market
- Banks' balance-sheet costs (size-based)
  - ◇ Examples: Supplementary Leverage Ratio (SLR), Federal Deposit Insurance (FDIC) fee
- Lenders' bargaining power
  - ◇ Example: Federal Home Lending Banks (FHLB) & MMFs' outside option (eg, ONRRP)

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Reserve Demand Curve: Theory

- Non-linear reserve demand curve with vertical and horizontal shifts:

$$p_t = p_t^* + f(q_t - q_t^*; \theta) + \epsilon_t$$

  - $\diamond$ p_t: spread between federal funds rate and IORB
  - $\diamond$ q_t: ratio of aggregate reserves to bank assets
  - $\diamond$ p_t^*: vertical location (curve's lower bound)
  - $\diamond$ q_t^*: horizontal location
  - $\diamond$ $f(\cdot; \theta)$ decreasing nonlinear function, parameterized by time-invariant θ

Estimating the Slope of the Reserve Demand Curve

- Structural demand curve at daily frequency:

$$p_t = \alpha_t + \beta_t q_t + \sigma_t \upsilon_t$$

  - p_t: spread between federal funds rate and IORB
  - q_t: ratio of aggregate reserves to bank assets
  - β_t: elasticity of reserve demand (slope)

- Idea: time-varying parameters capture non-linearity & low-frequency shifts

- Assumption: parameters move more slowly than daily demand shocks (υ_t)

First Type of Endogeneity: Fed's Interventions

- Fed adjusts reserve supply in response to unusual price dislocations
  - ◇ Examples: September 2019, March 2020
- Response is quick but with delay of at least one day
- Prices respond quickly returning to prior level within days

Second Type of Endogeneity: Non-Reserve Liabilities

1. Changes in non-reserve liabilities mechanically affect level of reserves

2. They can also correlate with reserve-demand shocks!

- Non-reserve liabilities are used by key money-market participants
  - ◇ Treasury (TGA), MMFs (ONRRP), FHLBs (ONRRP, Fed accounts)

- September 2019 (repo-market spillover), 2021-2022 (ONRRP take-up)

Example: Banks' Window-dressing

- Month-ends: European banks reduce wholesale short-term borrowing

  $\Rightarrow$ Downward pressure on reserve demand

- MMFs place more cash at ONRRP

  $\Rightarrow$ Reserves decrease

- Window-dressing of European banks reverts within few days

Example: Treasury Auctions

- Settlement dates: banks' demand for overnight funding increases

  $\Rightarrow$ Upward pressure on reserve demand

- Banks send reserves to the Treasury (TGA) for the securities

  $\Rightarrow$ Reserves decrease

- Transient but frequent confounding factor

$\diamond$ Similar: corporate tax payments

Estimation: Instrumental Variables (IV) Approach

1. Forecasting model of joint dynamics of reserves (q) and rates (p)
   - ◇ Time-varying VAR with stochastic volatility
   - ◇ Daily data; 10 lags
   - ◇ Bayesian estimation
   - ◇ Coefficients follow random walk slower than daily shocks
   - ◇ Good out-of-sample (OOS) accuracy

2. Five-day-ahead reserves' forecast errors as instrument

3. Estimated $\widehat{\beta}_t^{(IV)}$ derived from Bayesian estimation of TV-VAR

Our IV Methodology

- Estimate TV-VAR $\rightarrow$ reserves' forecast errors $u_{q,t} = q_t - q_{t|t-1}$
- Use error $u_{q,t-5}$ as instrument for q_t in structural equation:

$$s_t = \alpha_t + \beta_t q_t + \sigma_t \upsilon_t$$

$\Rightarrow$ IV estimate: $\widehat{\beta}_t^{(IV)} = \dfrac{\text{cov}_t(s_t, u_{q,t-5})}{\text{cov}_t(q_t, u_{q,t-5})}$

- Instead of usual 2SLS, pull back cov$(\cdot)$ from the inversion of a the reduced-form TV-VAR:

$$\Rightarrow \widehat{\beta}_t^{(IV)} = \frac{\text{GIRF}_{t,5} \text{ of rates to reserve}}{\text{GIRF}_{t,5} \text{ of reserves to reserve}} \left(\frac{\text{'reduced-form'}}{\text{'first-stage'}} \right)$$

Our IV Methodology in Detail (I)

- The forecasting model: time-varying vector autoregressive (TV-VAR) model with stochastic volatility (Primiceri, 2004):

$$q_t = c_{q,t} + b_{q,q,1,t} q_{t-1} + b_{q,p,1,t} p_{t-1} + ... + b_{q,q,m,t} q_{t-m} + b_{q,p,m,t} p_{t-m} + u_{q,t},$$

$$\mathrm{p}_t = c_{p,t} + b_{p,q,1,t} q_{t-1} + b_{p,p,1,t} p_{t-1} + ... + b_{p,q,m,t} q_{t-m} + b_{p,p,m,t} p_{t-m} + u_{s,t},$$

- The u's are the forecast errors.

$$(u_{q,t}, u_{p,t})' \sim \mathcal{N}(0, \Omega_t)$$

.

Our IV Methodology in Detail (II)

- Instead of usual IV estimation (2SLS)
- We directly pull back IV covariances from reduced-form VAR's estimation

$$q_t = \sum_{j=1}^{\infty} \psi_{q,q,j,t} u_{q,t-j} + \tilde{q}_t \quad \& \quad s_t = \sum_{j=1}^{\infty} \psi_{s,q,j,t} u_{q,t-j} + \tilde{s}_t$$

$\psi_{q,q,.}$ & $\psi_{s,q,.}$: GIRFs of reserves and rates to reserves
IRFs of reserves and rates to reserves shocks with recursive identification (q_t ordered first)

$\tilde{q}_t$, $\tilde{s}_t$: linear combinations of rates' forecast errors $u_{s,t}$

- Estimate VAR so that u_s are residualized wrt u_q
- Our IV estimate of rate elasticity to reserves: $\beta_t = \dfrac{\psi_{s,q,h,t}}{\psi_{q,q,h,t}}$

Exogeneity of Our Instrument: Daily Data Are Key

- Exclusion restriction: $u_{q,t-5}$ uncorrelated with υ_t (demand's error)

1. Fed's response to price dislocations has a delay of at least a day
   - ◇ And prices normalize quickly

2. Confounding factors via non-reserve liabilities last less than 5 days
   - ◇ Examples: Treasury auctions & tax payments

Relevance of Our Instrument

1. Persistence of reserves' path in our sample

2. Forecasting accuracy of our model (even OOS)

$\Downarrow$

- 5-day-ahead reserve-to-reserve IRF: significant throughout sample
  - $\diamond$ equivalent of first-stage in traditional IV

Advantages & Robustness

- Automatically robust to weak instruments (vs ordinary 2SLS)
  - $\diamond$ β's posterior already reflects uncertainty in denominator IRF
- Robust to autocorrelation & heteroskedasticity
  - $\diamond$ Ratio of IRFs estimated from VAR with 10 lags & stochastic volatility
- Robustness checks:
  - $\diamond$ Add confounders to forecasting model (repo, T-bill, MMF rates)
  - $\diamond$ Change reserves' normalization (GDP, bank deposits)

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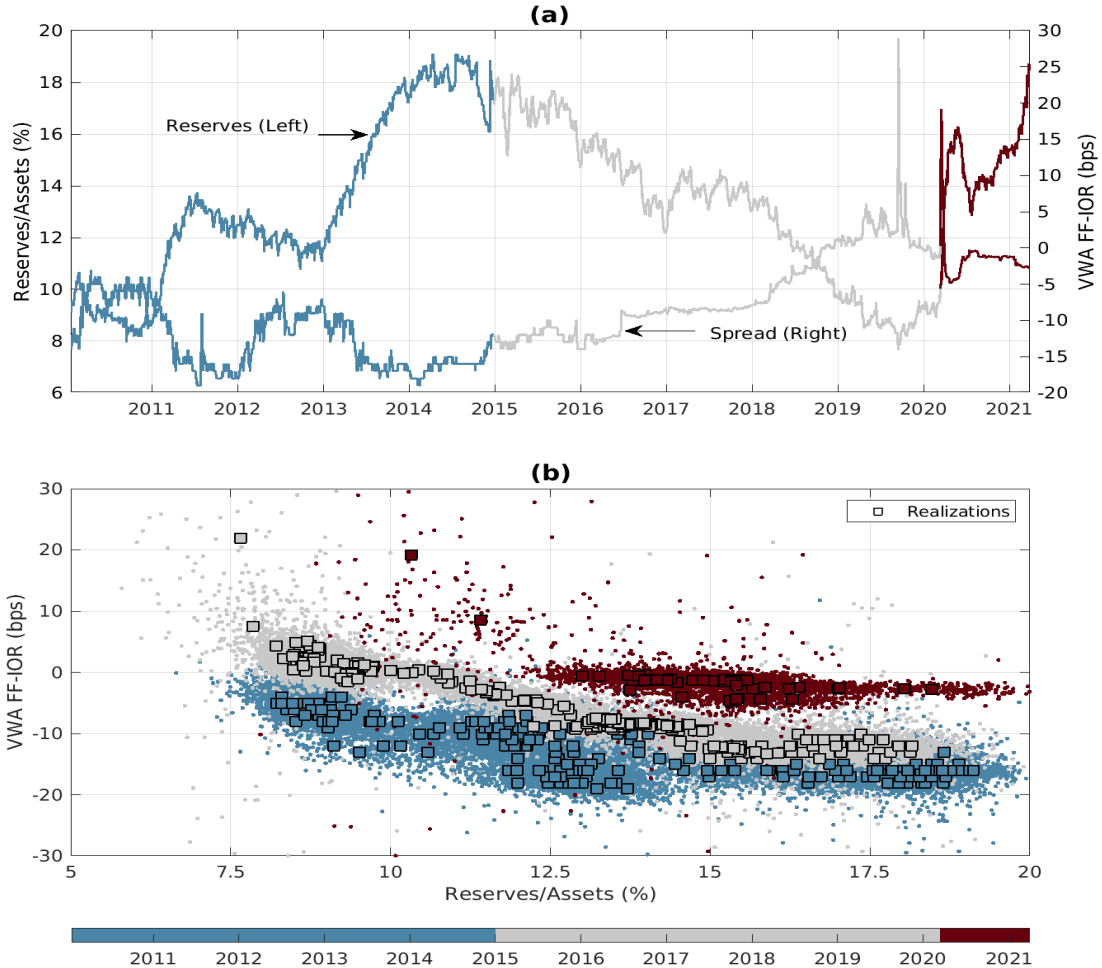
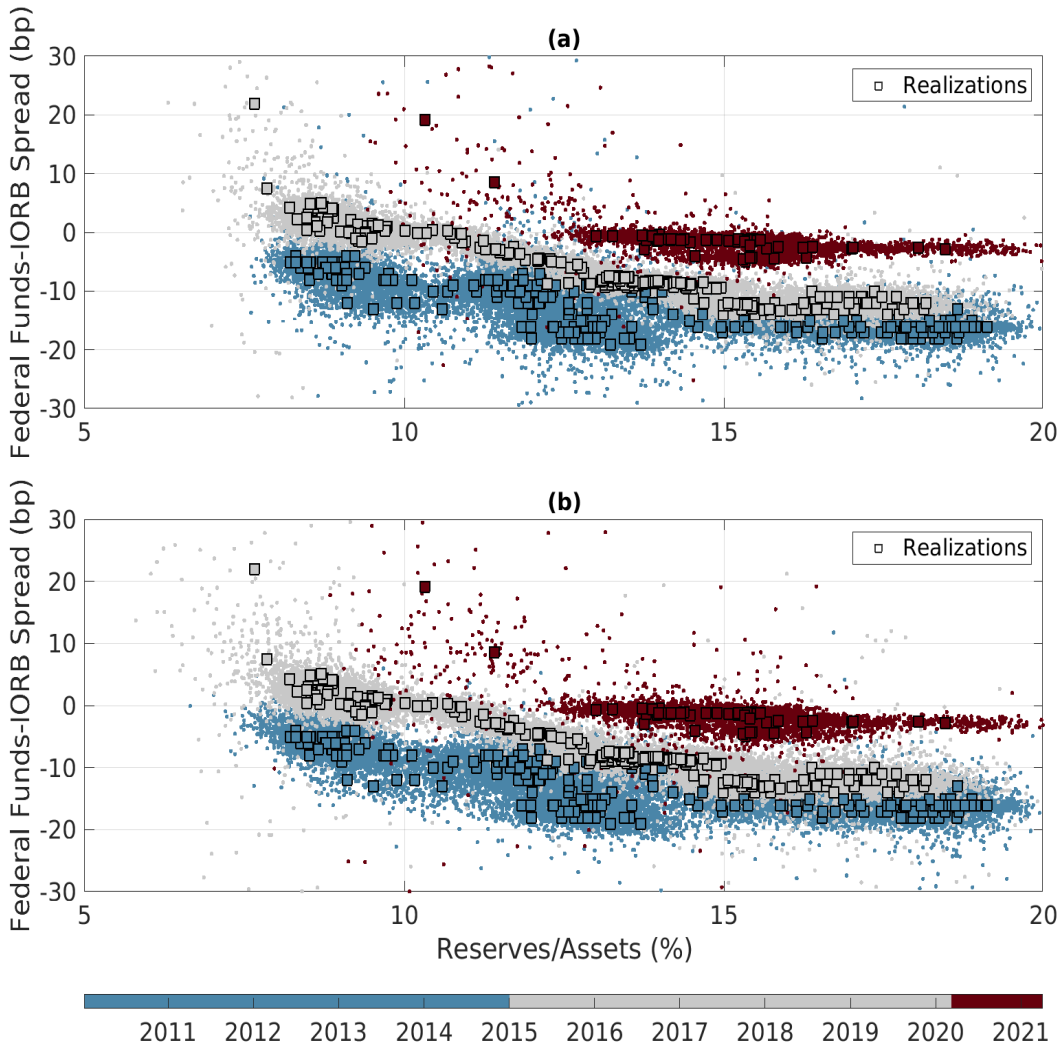
3. **Results**

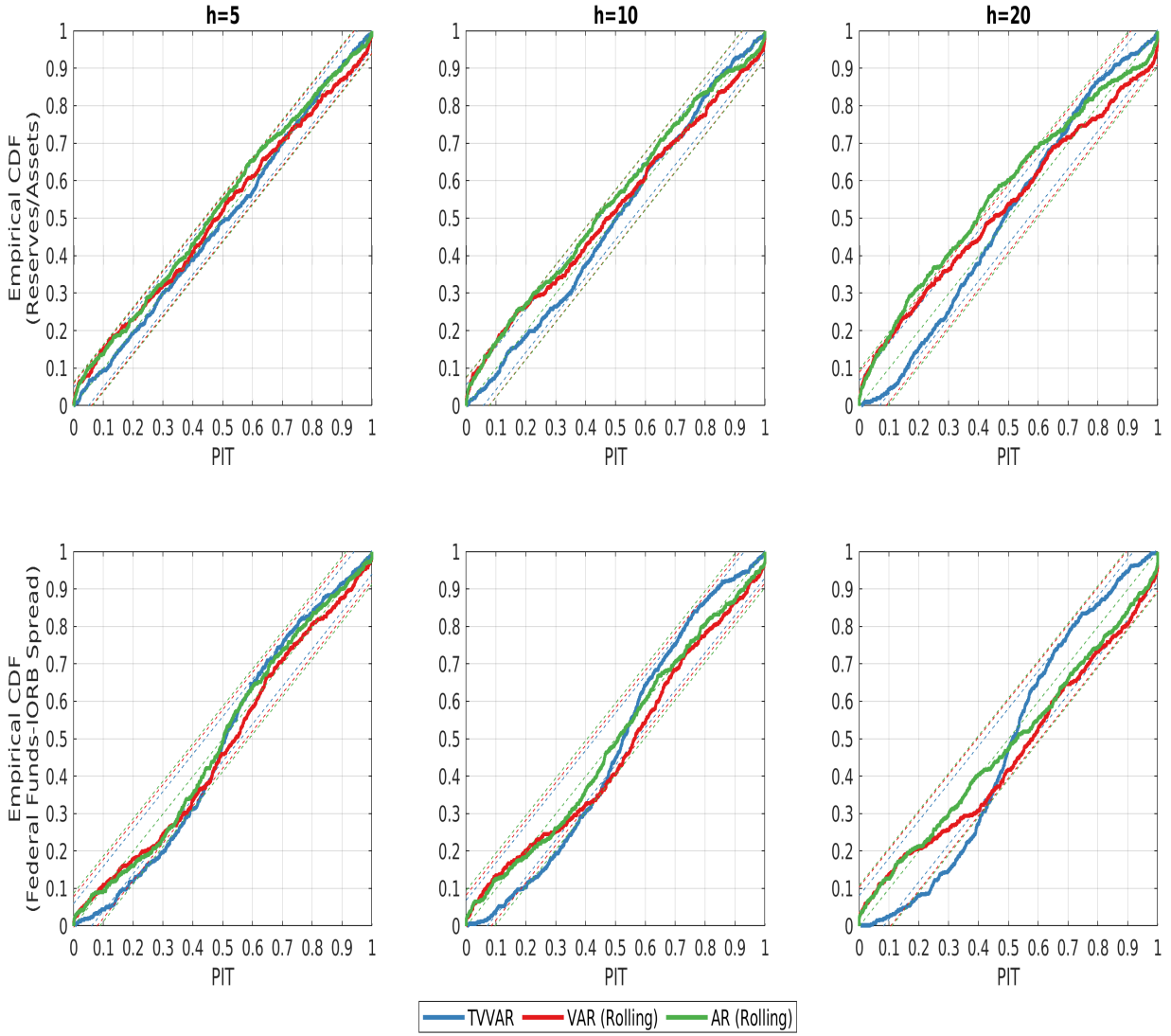
Out-of-Sample (OOS) Forecasting Accuracy



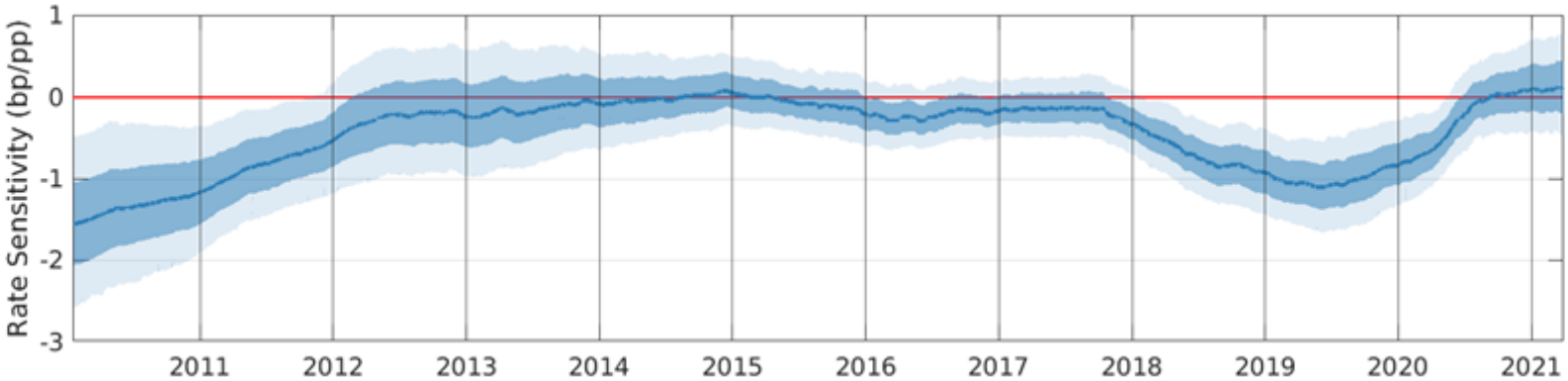
Out-of-Sample (OOS) vs In-Sample (IS)



Calibration



Estimated Slope of the Reserve Demand Curve

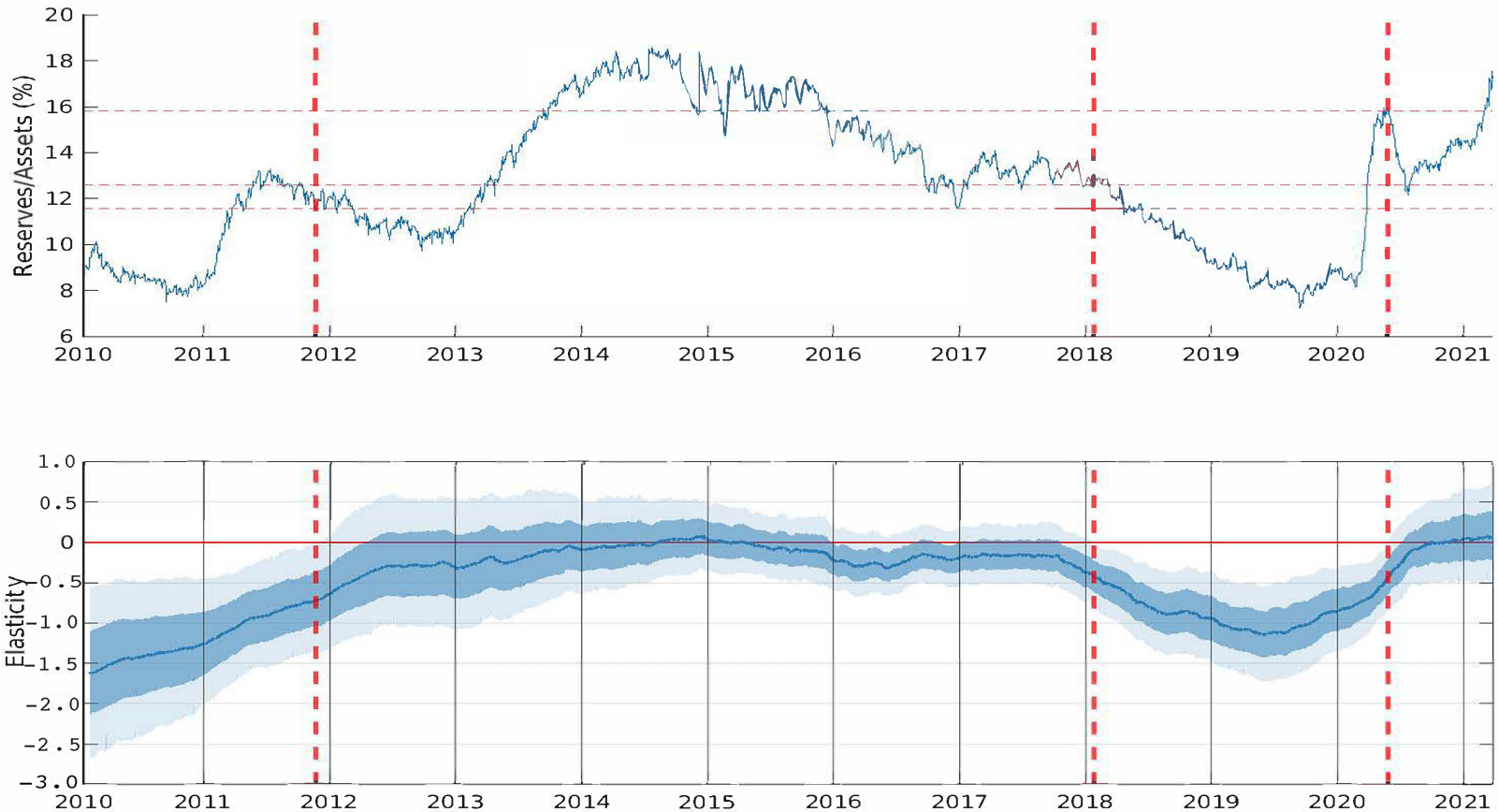


- Statistically significant negative slope in 2010-2011 and in 2018-2020H1
- Near-zero slope during 2012-17 and 2020H2-2021Q1

IRFs ▷ Oct 2022▷

From Abundant (Flat) to Ample (Gently Sloped)?

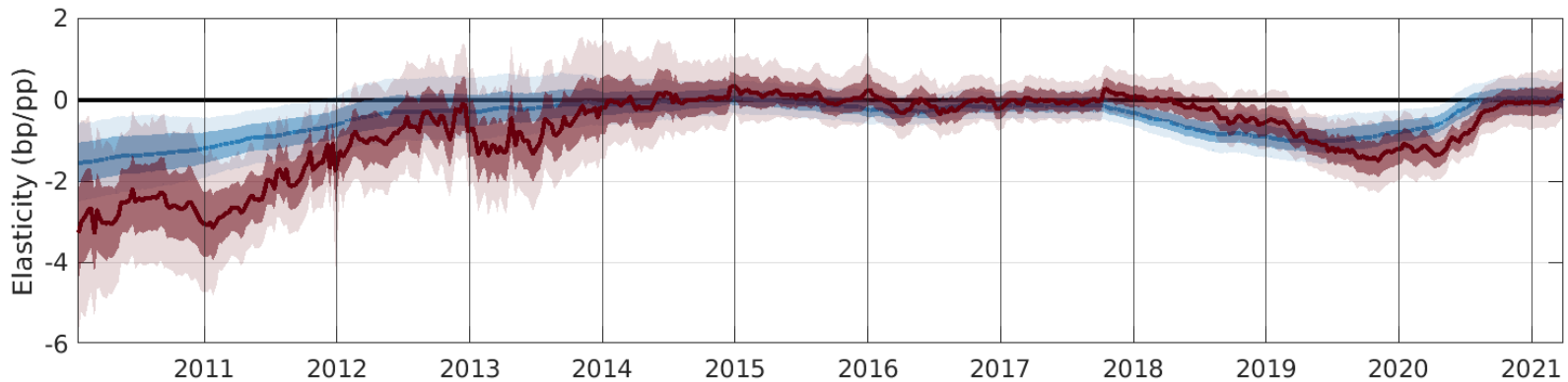
- Slope emerges around 12% of bank assets in 2011 and 13% in 2018
  - ◇ Reserves = \$1.6tn in 2011 and \$2.2tn in 2018



Real-time Monitoring of Reserve Ampleness

OOS IV estimate: expanding windows every 5 days

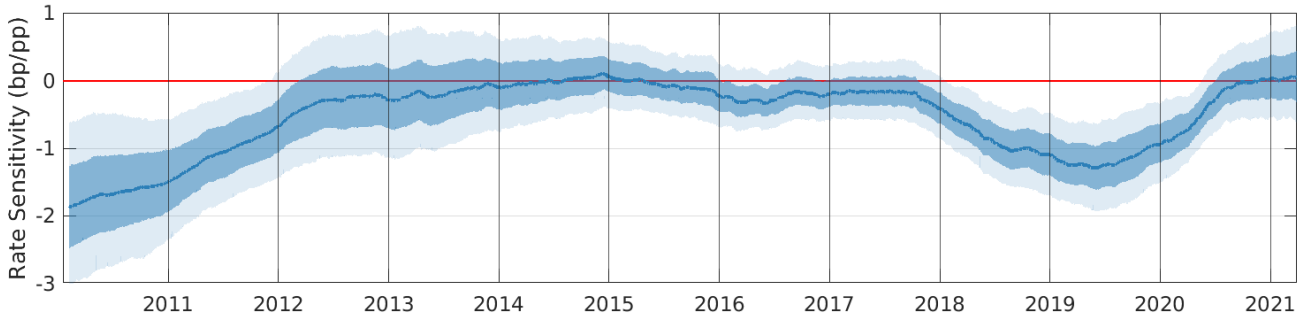
- Close to IS estimates
- Becomes significant in 2018Q3-2019Q1 (12-6 months before Sept 2019)



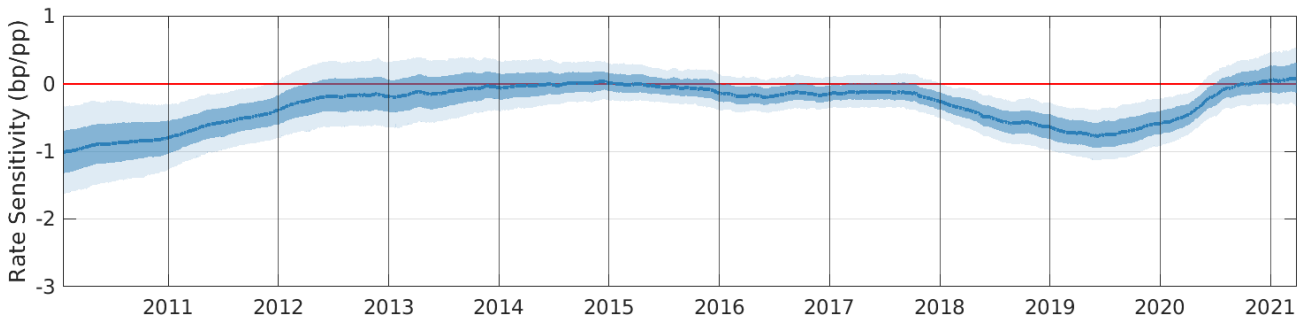
Up to Oct 2022 ▷

Robustness: Different Reserve Normalizations

- Normalizing reserves by GDP

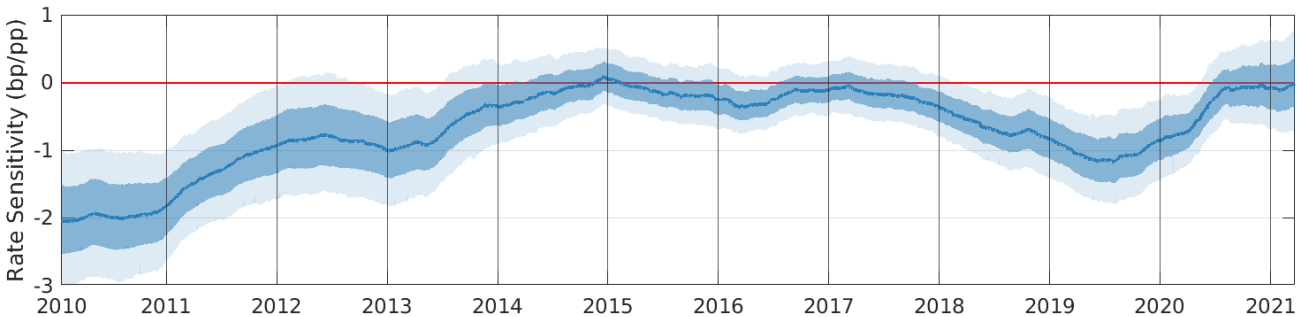


- Normalizing reserves by bank deposits

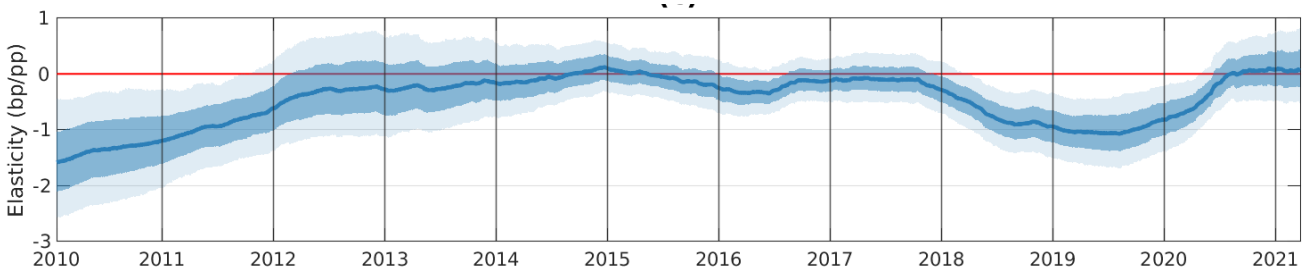


Robustness: Controlling for Other Market Rates

- Adding repo rates in TV-VAR (trivariate)



- Adding T-bill yields in TV-VAR (trivariate)



- Same with MMF rates

Quantifying Horizontal and Vertical Shifts in Demand

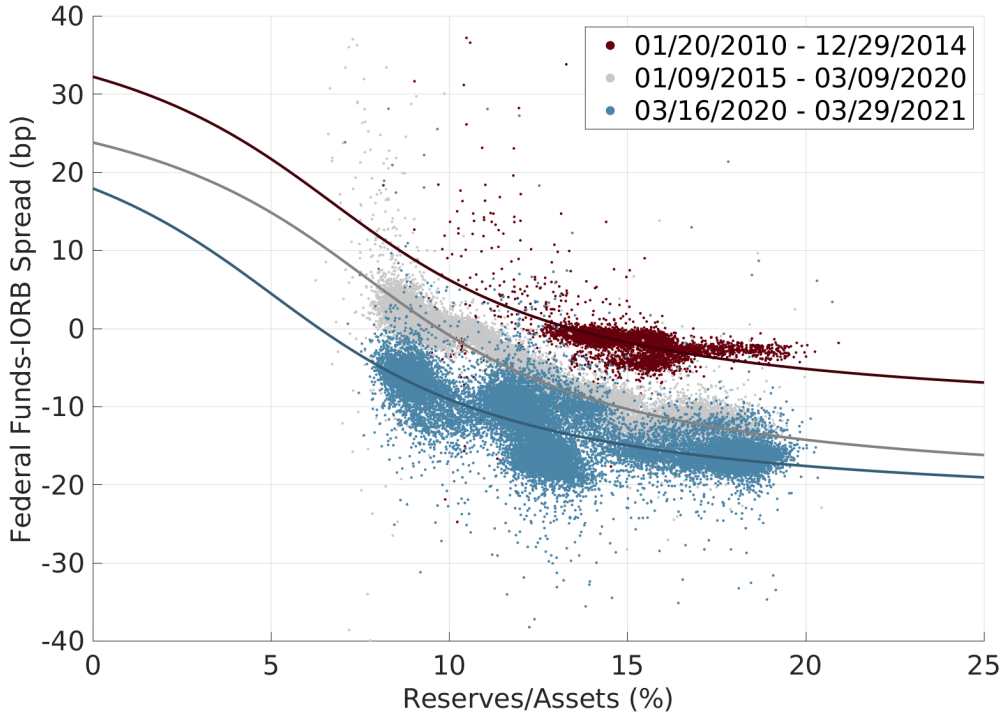
- Specify non-linear functional form with vertical & horizontal shifts
  - ◇ Only 3 periods for simplicity (but daily varying also possible)
- Non-linear fit on draws from time-varying forecasting model:

$$\hat{p}_{i,t} = p_t^* + f(\hat{q}_{i,t} - q_t^*; \theta) + e_{i,t}$$

$$f(x; \theta) = \left(\arctan\left(\frac{\theta_1 - x}{\theta_2} \right) + \frac{\pi}{2} \right) \theta_3$$

  - ◇ $\hat{p}_{i,t}$ and $\hat{q}_{i,t}$: forecast draws ($i = 1, \ldots, N$ for each t)
  - ◇ p_t^*: vertical location (curve's lower bound)
  - ◇ q_t^*: horizontal location

Post-processing Non-linear Fit on Model Forecasts



- Horizontal shift to the right: 1-2 percentage points
- Vertical shift upward: 12-13 basis points

  $\Rightarrow$ Spread by itself is not a reliable summary statistic of rate sensitivity

Up To Oct 2022 ▷

Possible Drivers of Horizontal and Vertical Shifts

- Horizontal shifts:
  - ◇ Post-crisis liquidity regulation
  - ◇ Post-crisis changes in internal liquidity-risk management
  - ◇ Precautionary demand due to lack of depth in late-day market
- Vertical shifts:
  - ◇ Bargaining power of key lenders such as FHLBs & MMFs
  - ◇ Variation in banks' balance-sheet costs

From Ample (Gently) to Scarce (Steeply Sloped)?

- Non-linear post-processing fit allows to look at ample-to-scarce transition
  - ◇ IV structural estimates can't because they are locally linear

- Point of maximum slope growth ($\theta_1 + \theta_2/\sqrt{3}$):
  - ◇ Slope changes from gentle to steep
  - ◇ 8-10% pre 2015 & 10-12% post 2015

Conclusions

- Methodology to identify abundant, ample, and scarce reserves in real time
- Time-varying estimates of demand elasticity:
  - ◇ Large elasticity $\rightarrow$ "scarce" reserves (2010, 2019)
  - ◇ Near-zero elasticity $\rightarrow$ "abundant" reserves (2012-2017, 2020-now)
  - ◇ Intermediate elasticity $\rightarrow$ "ample" reserves (2011, 2018)
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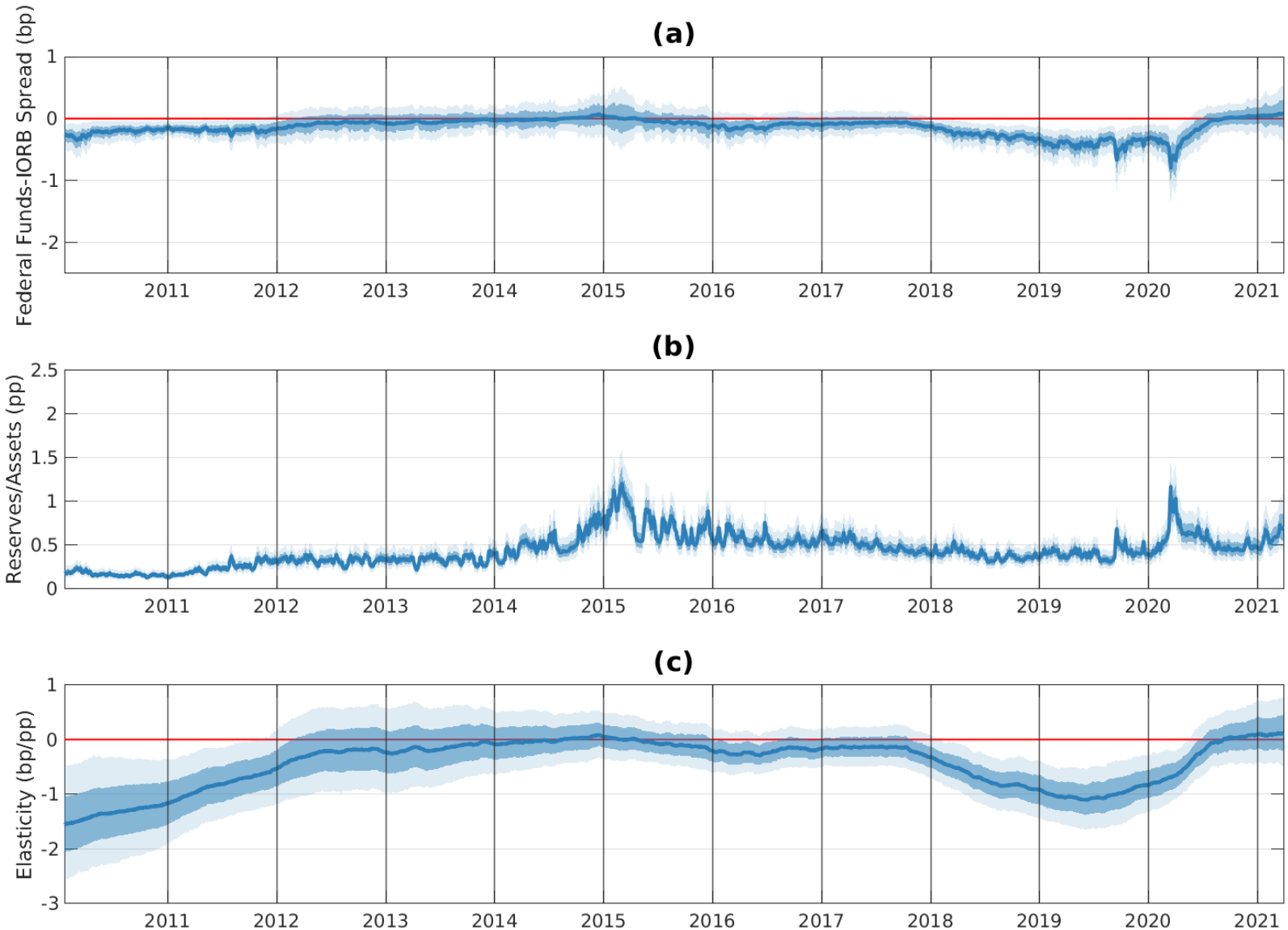
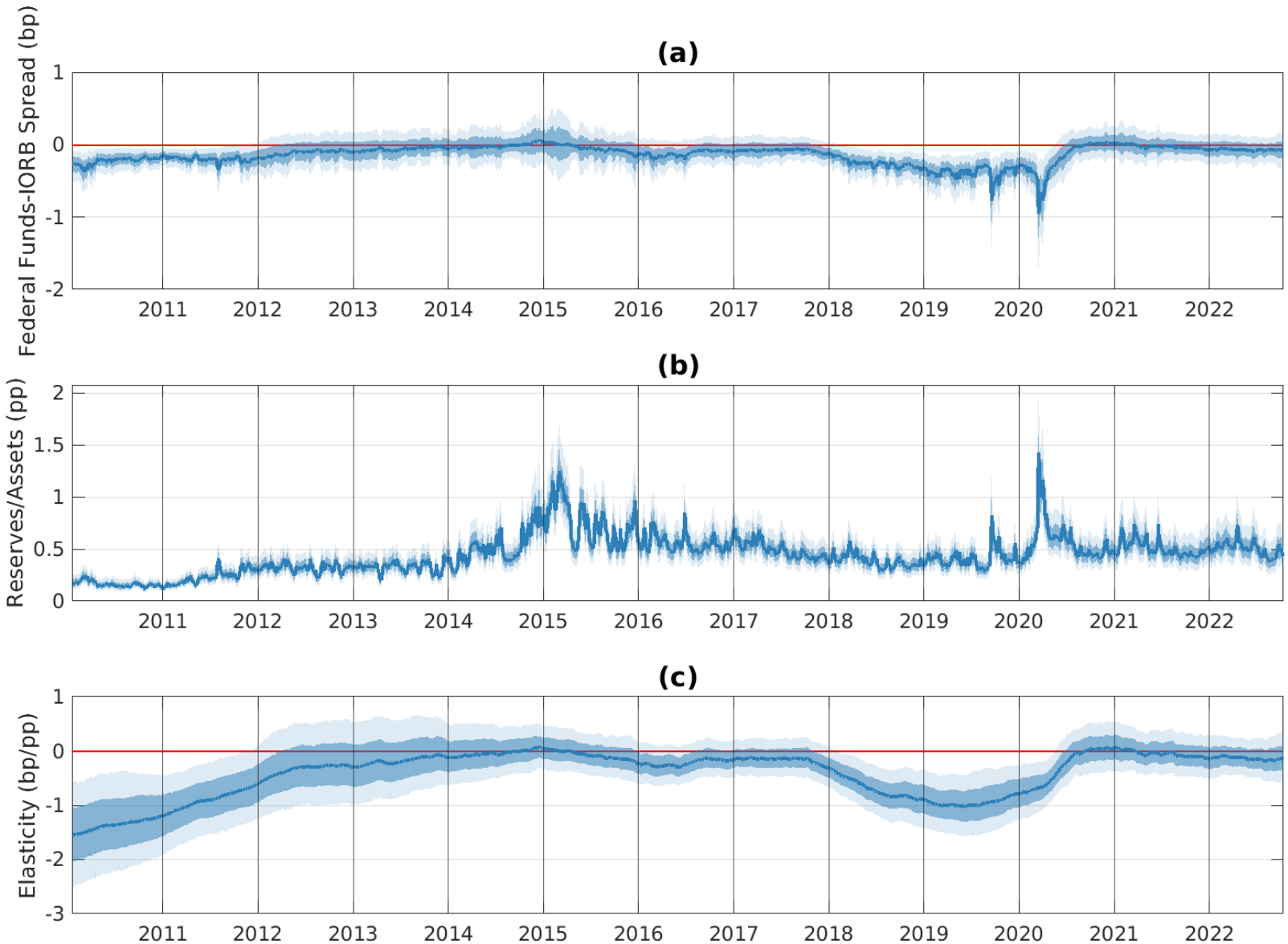
Numerator and Denominator of IV Estimate



Estimated Slope Up To October 2022



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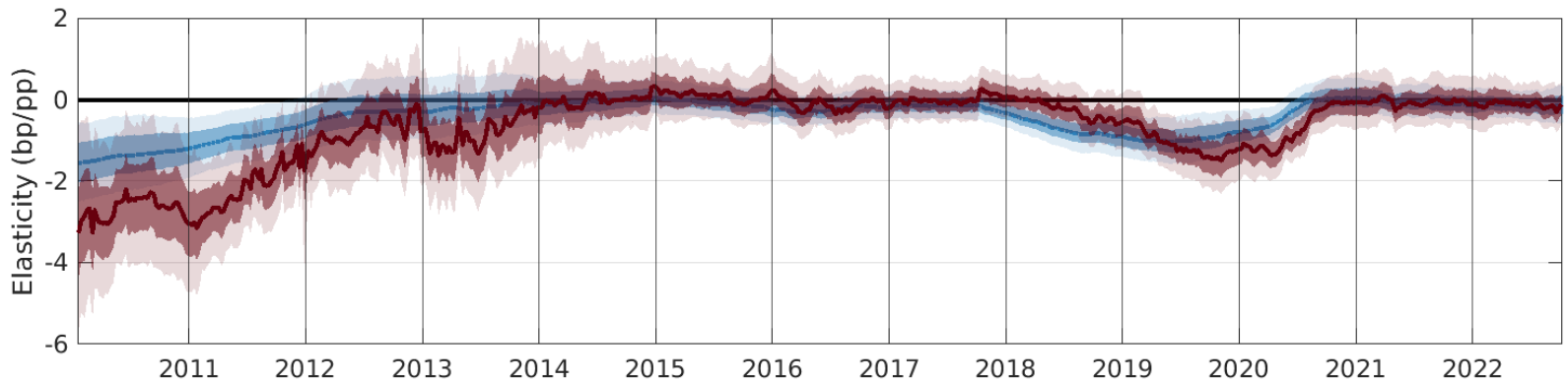

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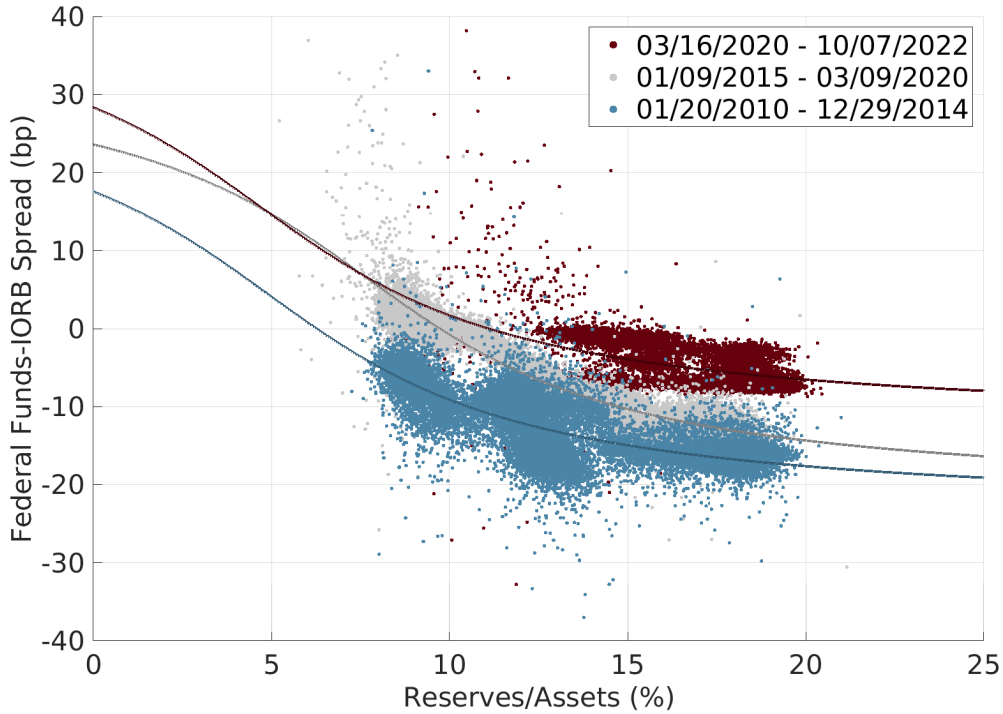

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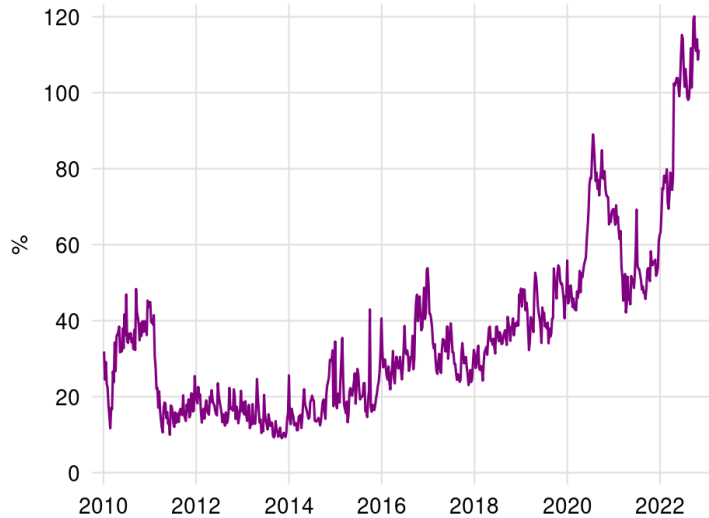
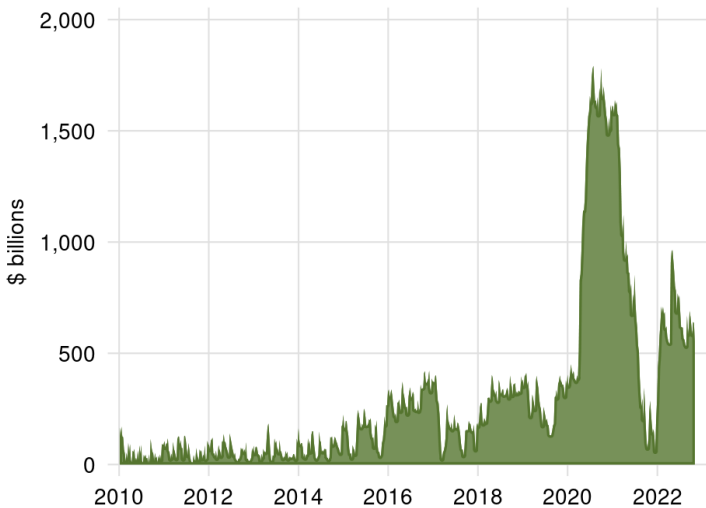
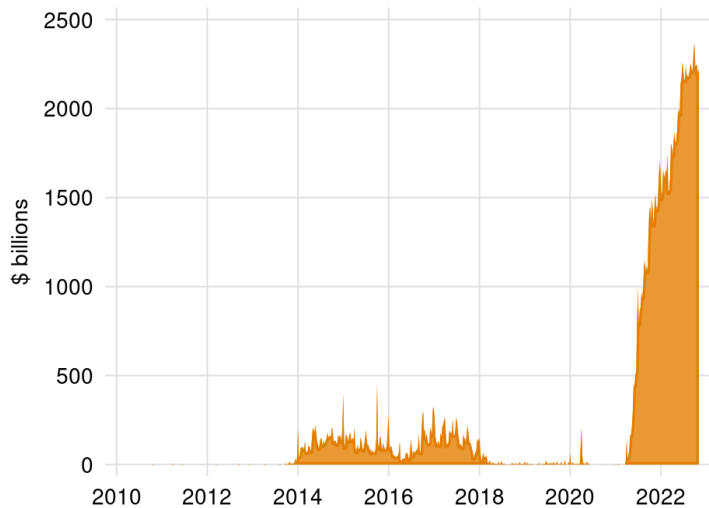
The Growth of Non-Reserve Liabilities



Non-Reserves/Reserves



TGA



ONRRP

Overnight Reverse Repo Facility (ON RRP)

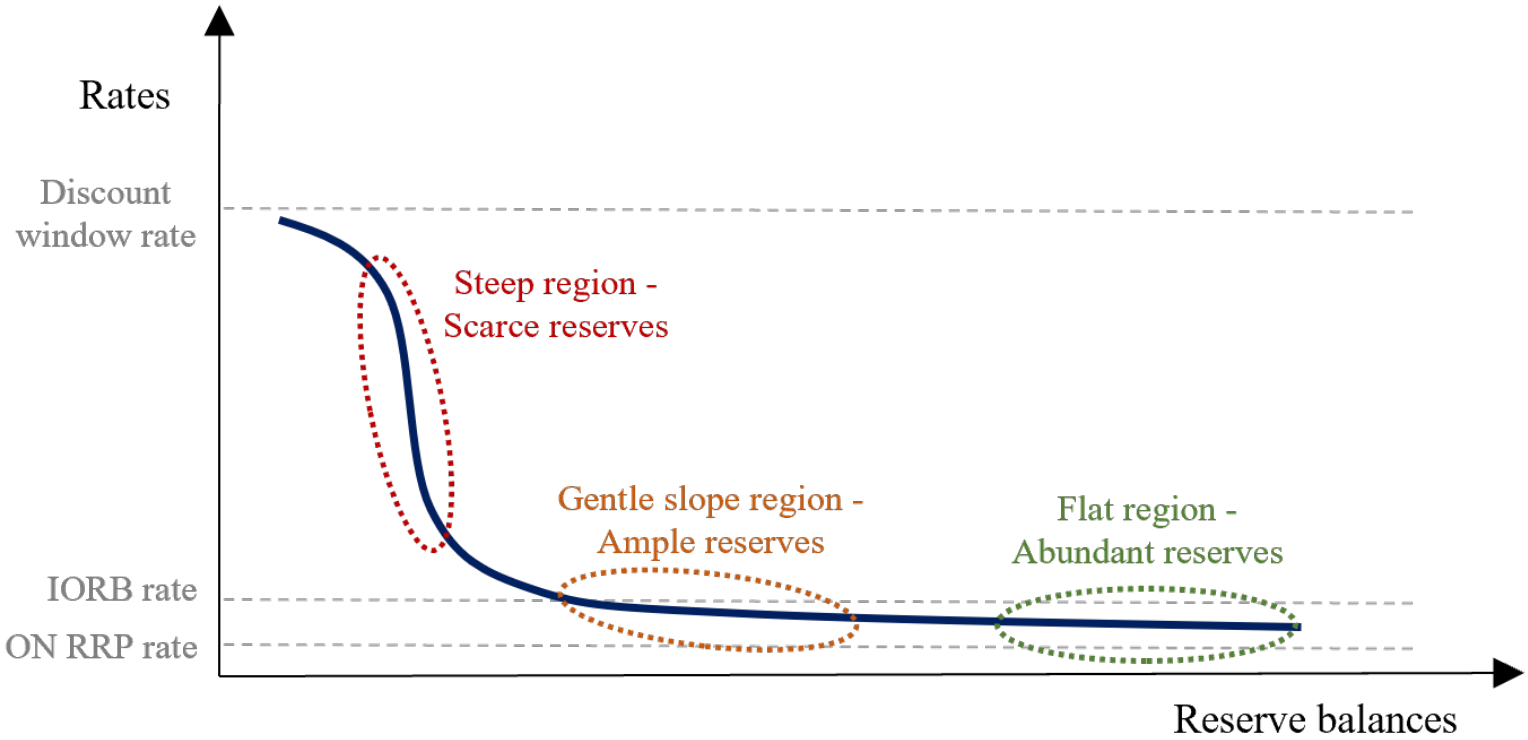


Figure: **Reserve demand curve (theory).**

- 2013: Fed introduced ONRRP for FHLBs & MMFs $\rightarrow$ floor on rates

Reserves in the U.S. Banking System