The Implementation of Monetary Policy:
How Do Central Banks Set Interest Rates?

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Japan Society of Monetary Economics
Tokyo: May 29, 2011

This lecture is based on my joint work with Kenneth N. Kuttner (Williams College).

See in particular our chapter in the *Handbook of Monetary Economics*, vol. 3 (Friedman and Woodford, eds.), 2011.

Motivation for the discussion (1)

- A surprising vacuum in our understanding:
  - “Monetary policy” now mostly means setting a short-term interest rate…
  - …but there is no good model of how central banks do that.
  - The traditional textbook model no longer corresponds to the reality of what central banks do.
  - Most professional-level analysis simply skips the subject altogether (the Taylor Rule literature, the literature based on the Clarida-Gali-Gertler model, etc.).
  - So do most graduate textbooks (e.g., Woodford, Romer).

Motivation for the discussion (2)

- Also, some important current policy issues:
  - Response to the crisis: huge increase in the size of central bank balance sheets. Was this action effective?
  - The “exit strategy” question: common presumption that the central bank needs to "unwind" these positions before it raises interest rates.
  - Does the central bank really have to do that?
  - Or can it go ahead and raise interest rates without having to sell off the securities it bought?
  - More fundamentally: what is the relationship between quantity and price (the interest rate) in the reserves market?

Motivation for the discussion (3)

- And a fundamental issue of monetary theory:
  - Does the quantity of central bank liabilities matter, including for inflation?
  - If so, will the large increases in many central banks' balance sheets prove inflationary?
  - If not, what's left of the classical quantity theory?

Outline for today's lecture

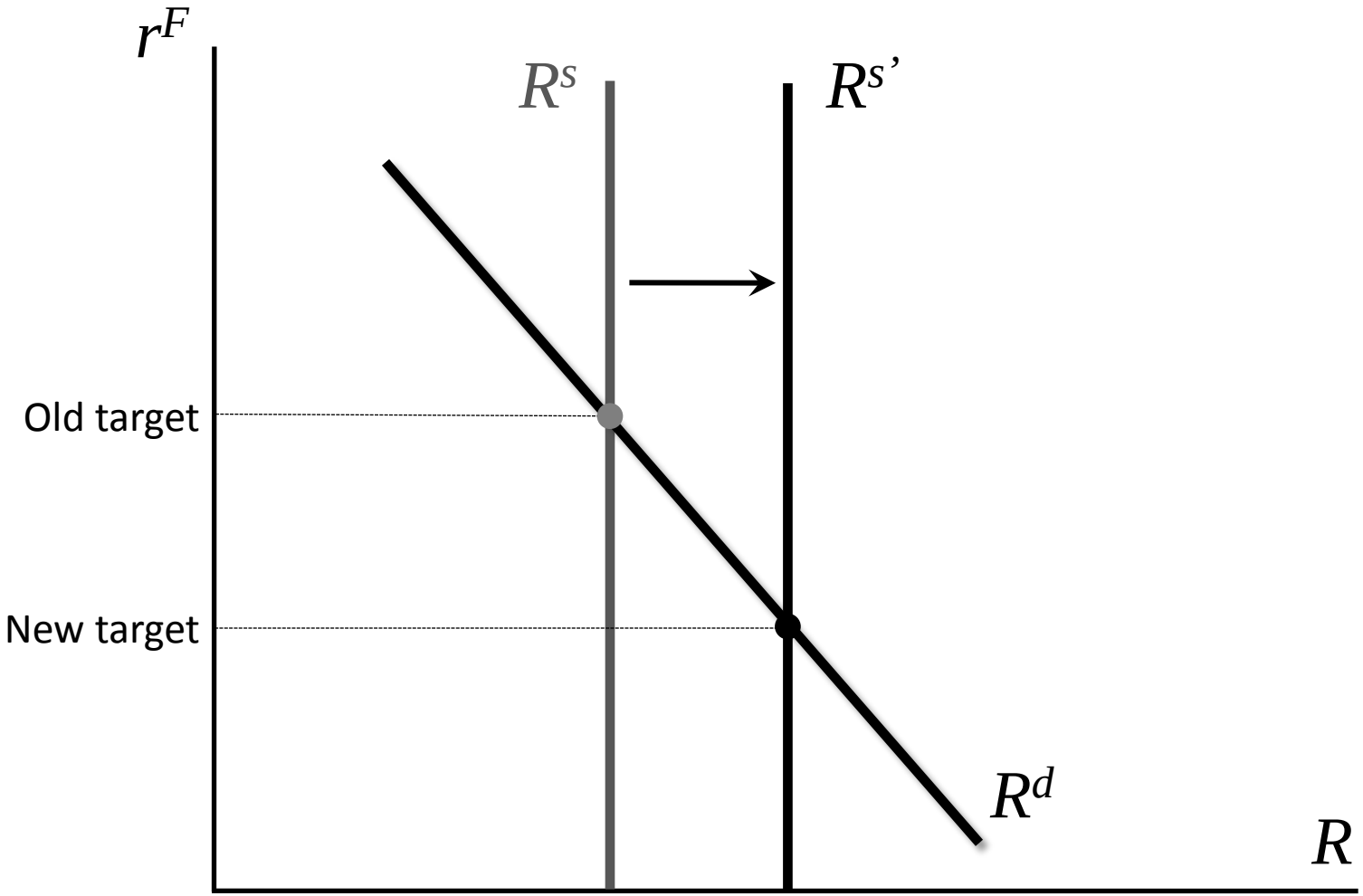
1. The traditional understanding of how central banks set interest rates.
2. This understanding has become obsolete.
3. A different model of how central banks set interest rates today.
4. Evidence supporting this alternative model.
   - the U.S.
   - Japan
   - the Euro-area

5. Implications for the “exit strategy” question.
6. Assessment of the effectiveness of central bank securities purchases (“quantitative easing”) during the crisis.
7. Some broader implications for monetary economics.

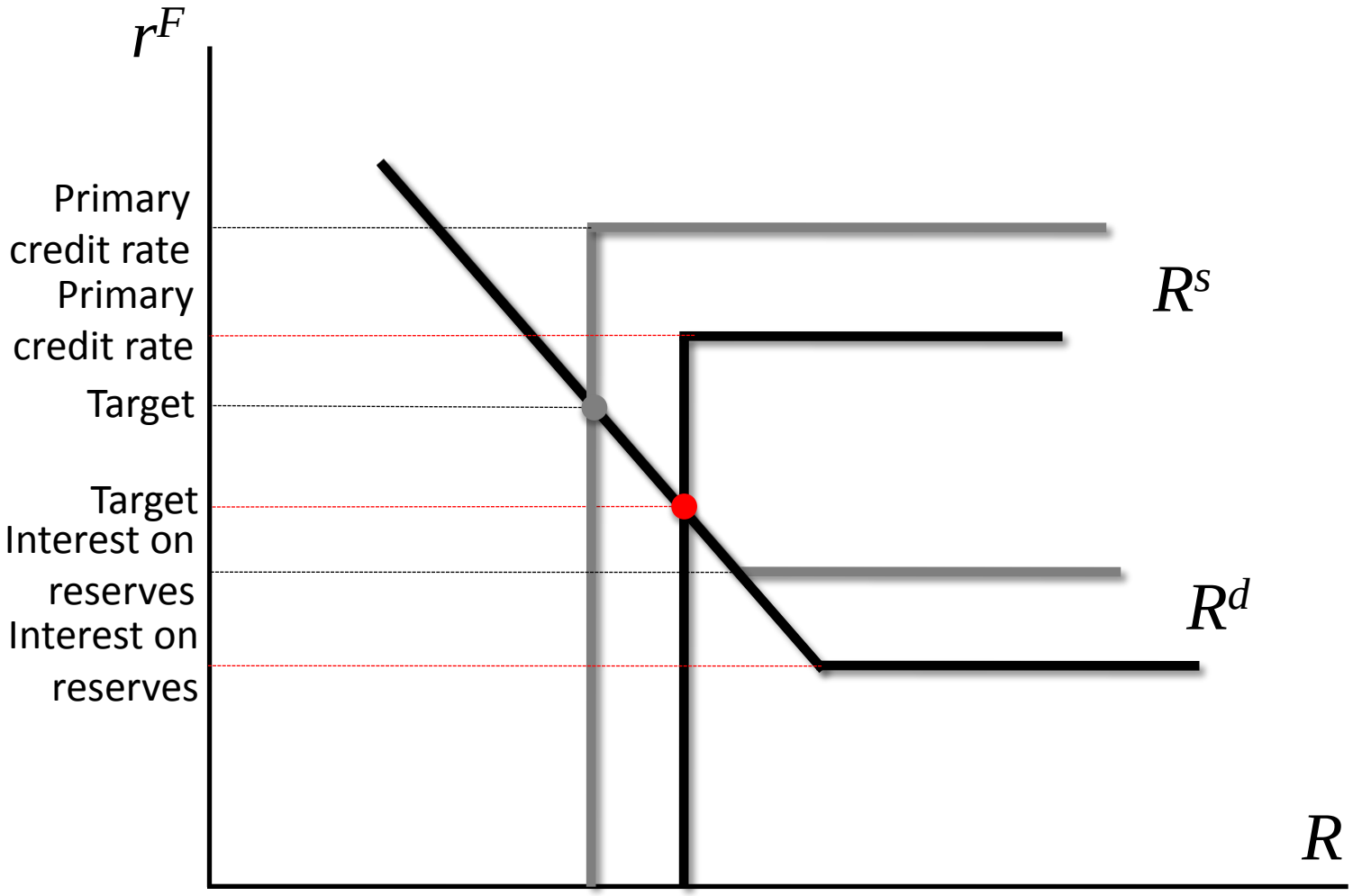
The traditional view of how central banks set interest rates

- When the central bank wants to move the overnight interest rate, it changes the quantity of reserves (*R*).
- Banks' demand for reserves is interest elastic.
- The change in *R* therefore induces a change in the interest rate (the "liquidity effect").

The traditional view



With borrowing & interest on reserves



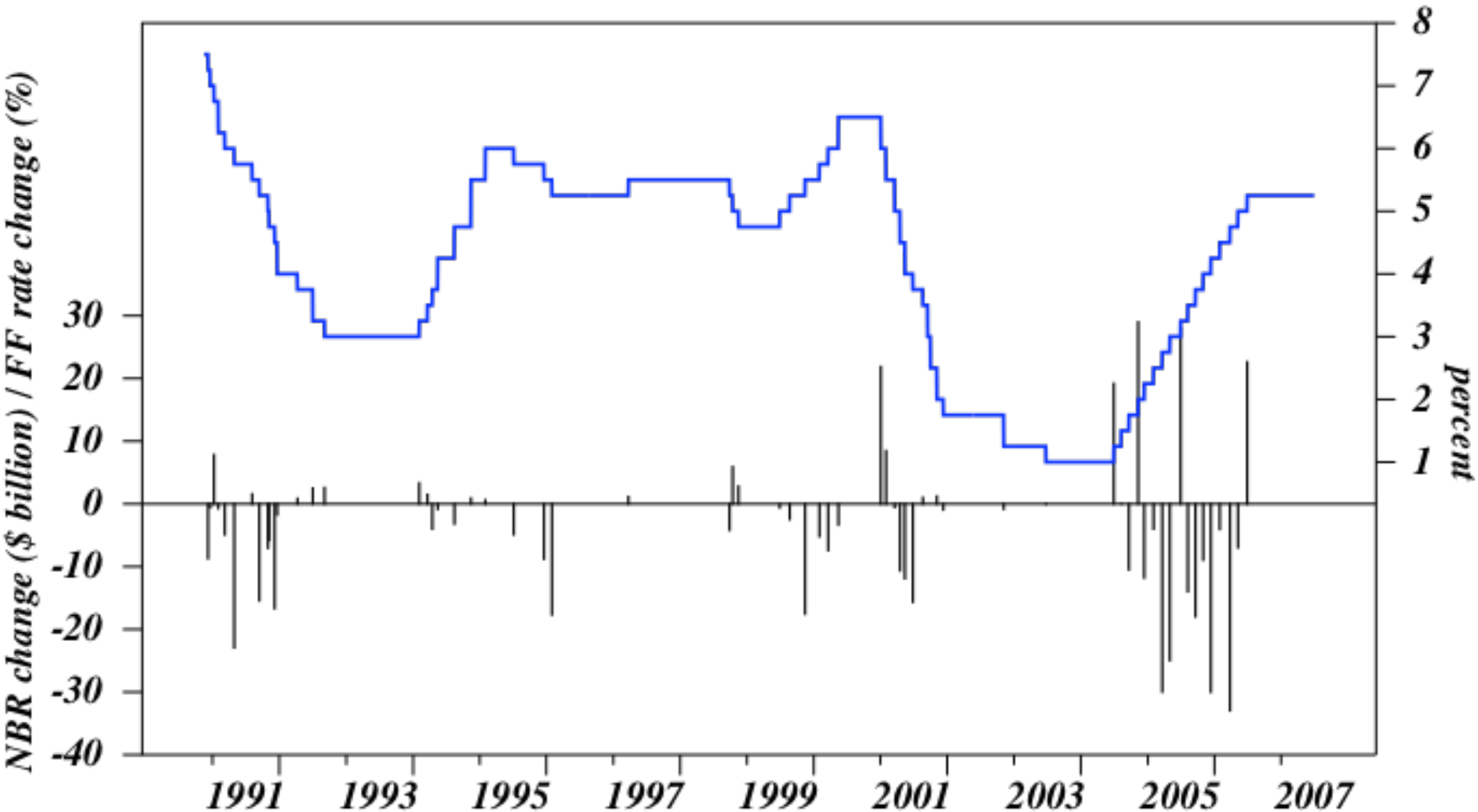
Evidence for a liquidity effect

- Quarterly or monthly monetary VARs:
  - Christiano & Eichenbaum (1992 and sequels)
  - Strongin (1995)
  - Bernanke & Mihov (1998)
- High frequency (daily) regressions:
  - Hamilton (1996 and sequels)
  - Carpenter & Demiralp (2006a & 2006b)

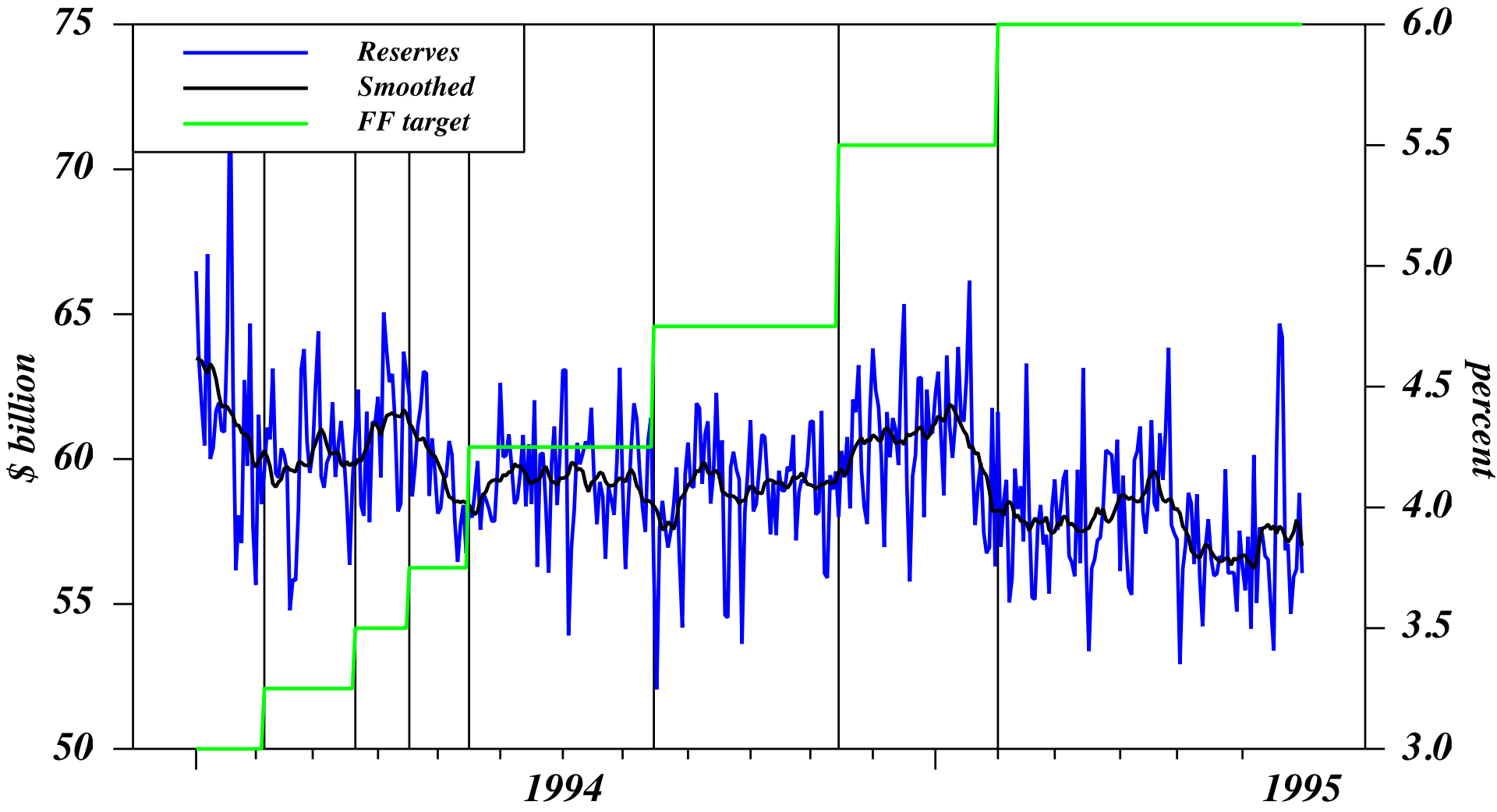
The vanishing liquidity effect

- Hamilton (1997): 23 b.p./$billion
- Hamilton (1998): 7 b.p./$billion
- Carpenter & Demiralp (2006b): 3.5 b.p./$billion
- Hence implausibly *large* changes in reserves should be required to move the funds rate.
- Contradiction: in fact most changes in *R* are very *small*.
- Indeed, many changes in *r* are not systematically associated with discernable changes in *R* at all.

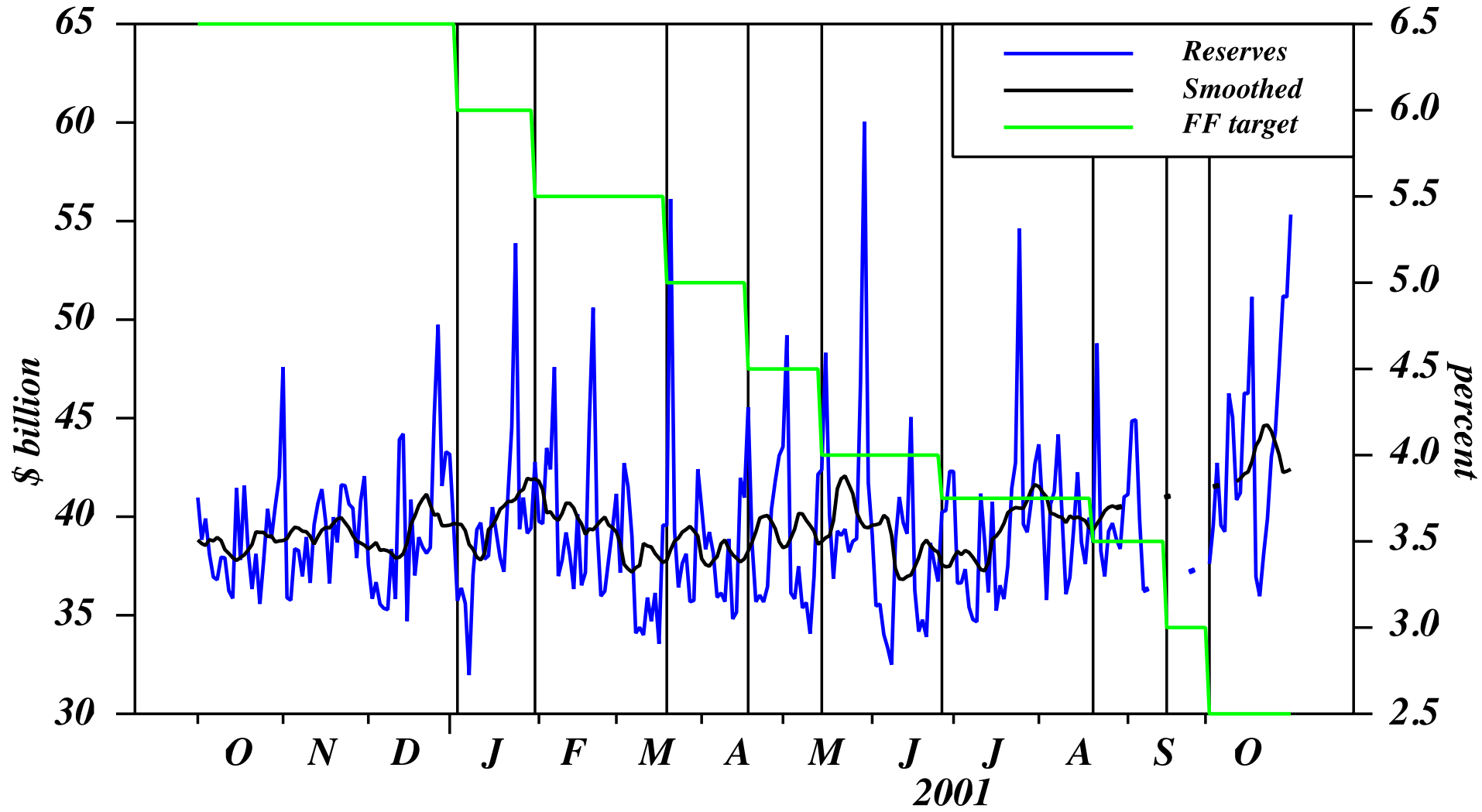
Scaled reserve changes and the U.S. FF rate



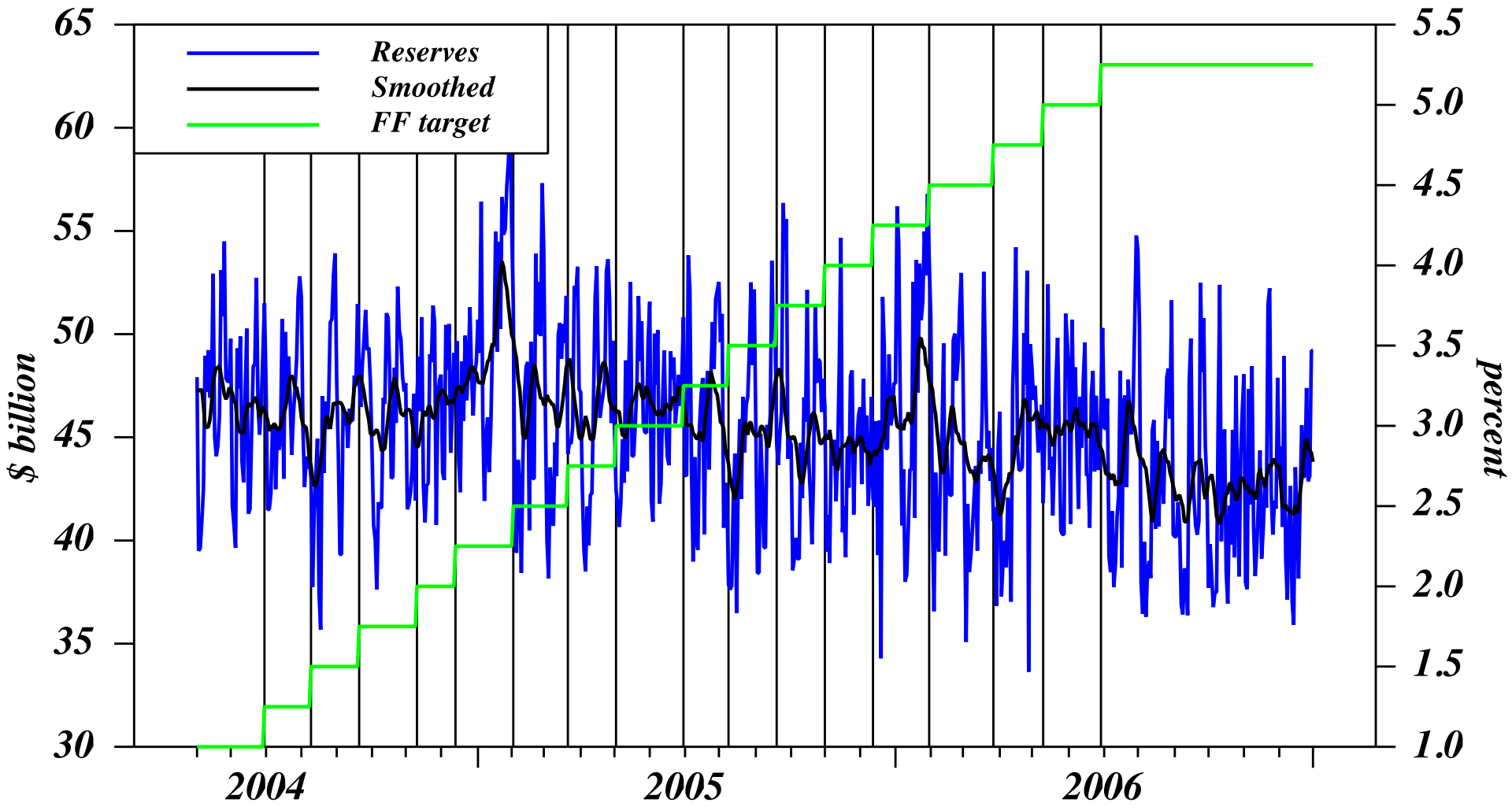
Reserves and the funds rate in 1994-95



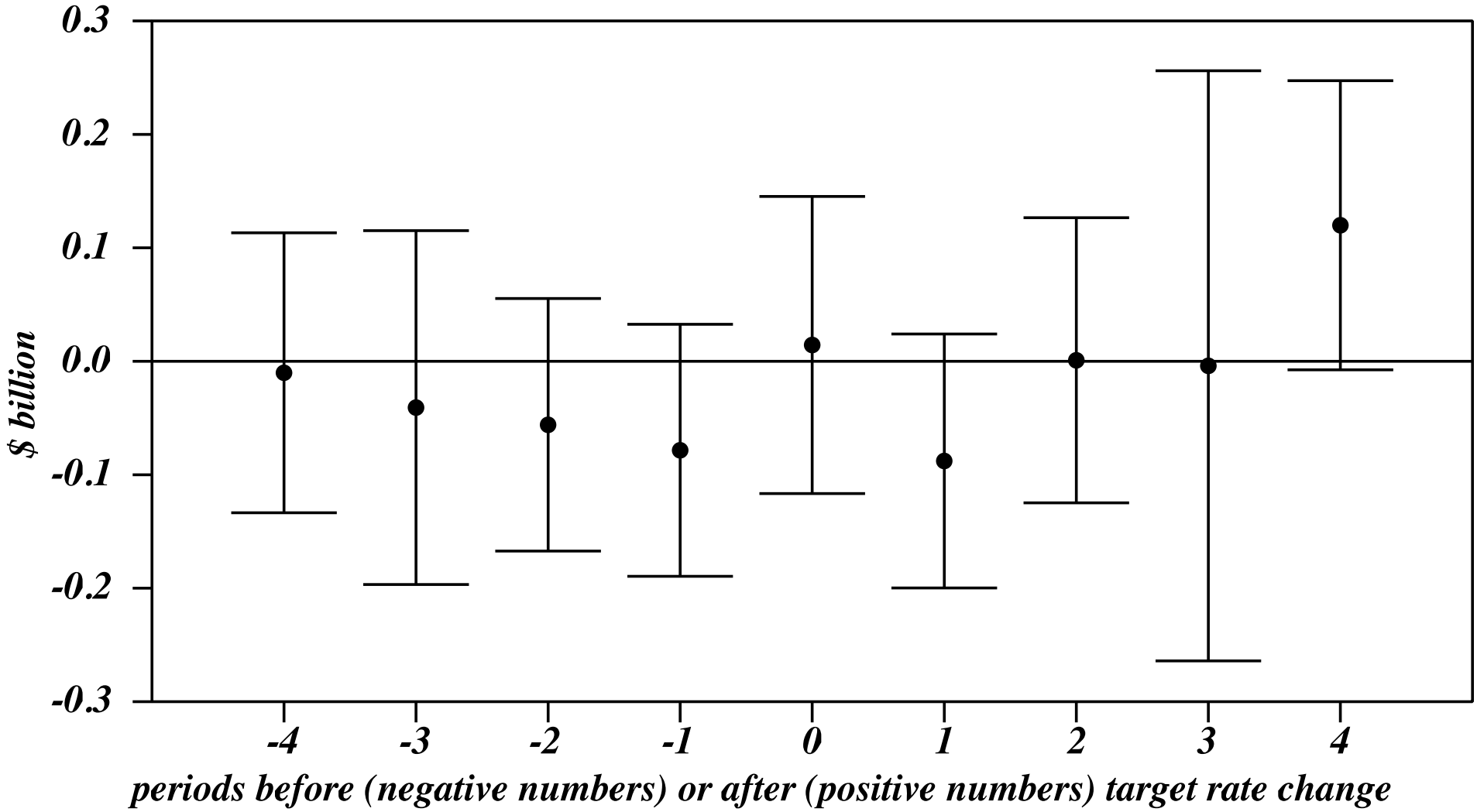
Reserves and the funds rate in 2000-01



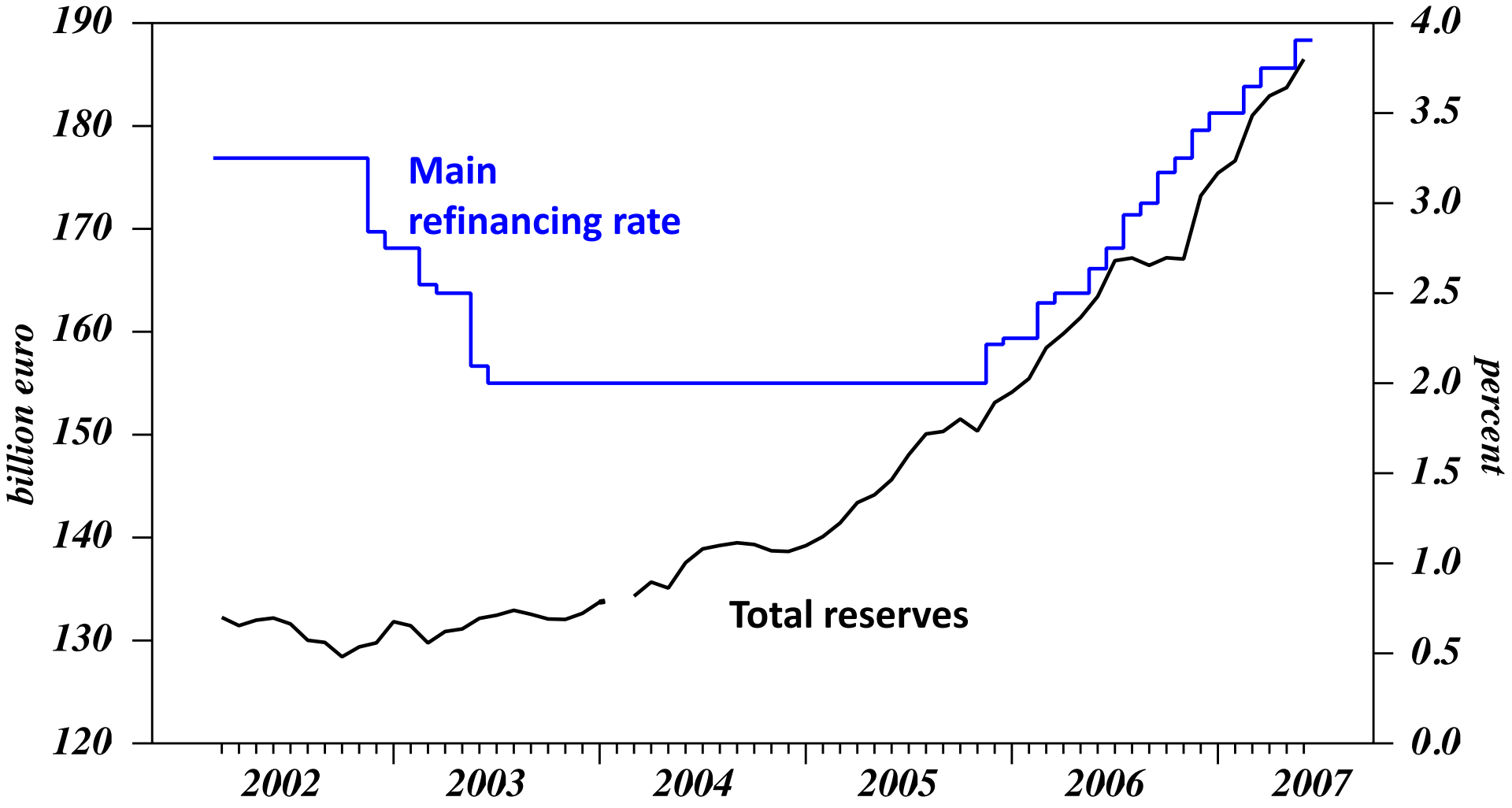
Reserves and the funds rate in 2004-06



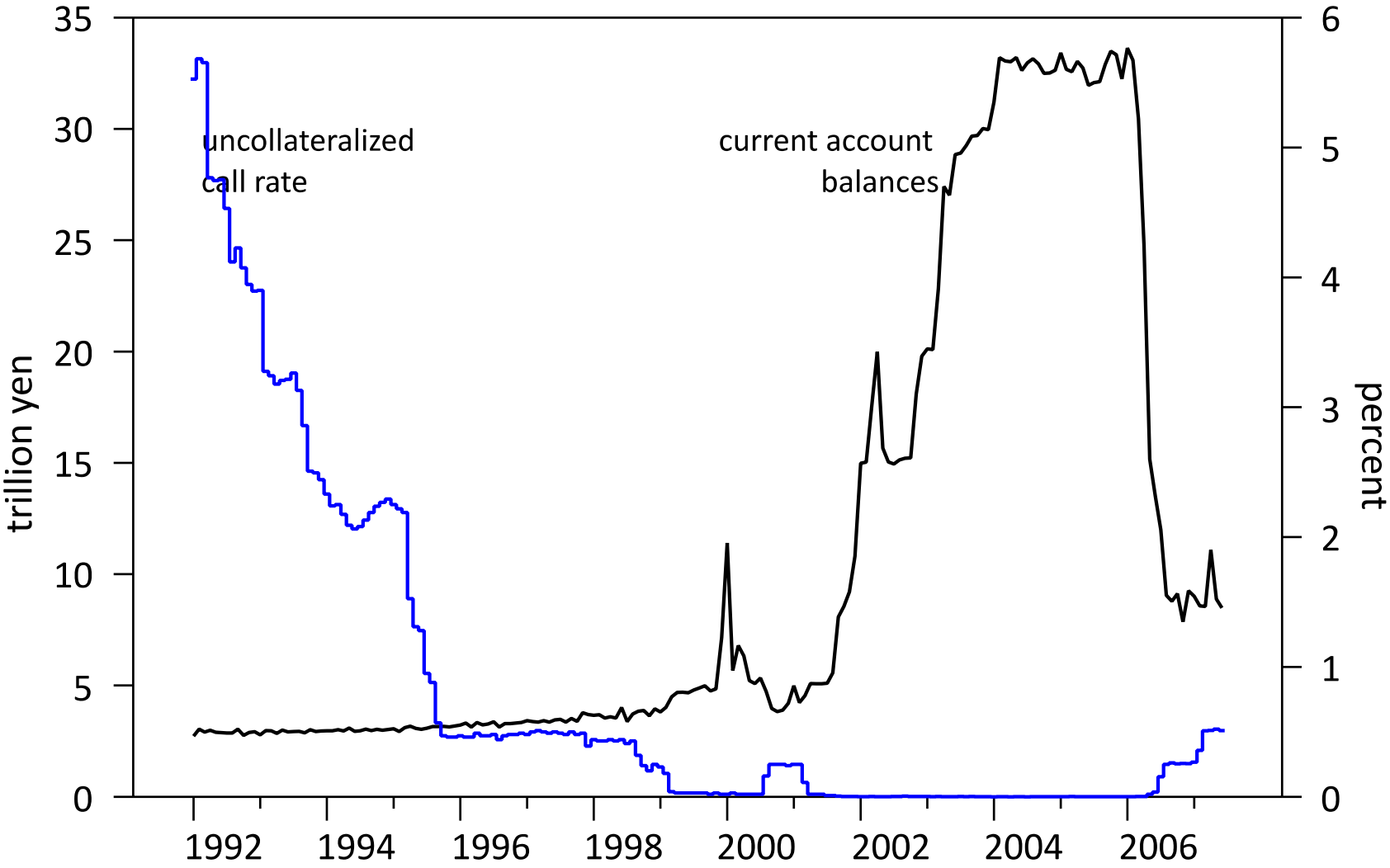
Reserves and target rate changes in the US



Euro area reserves and the interest rate



Reserves and the interest rate in Japan



Hence the question:

How *do* central banks set interest rates?

A new model of policy implementation

- Banks' reserve demand is very highly *in*elastic at low (biweekly or longer) frequencies.
  - This explains why changes in *r* are not associated with discernable changes in *R* over time.
- But: banks' reserve demand is very *elastic* at higher (daily) frequencies.
  - This explains why the measured daily liquidity effect is so small.
- Needed: a model to reconcile these two empirically based features.

Two key features of the reserves market

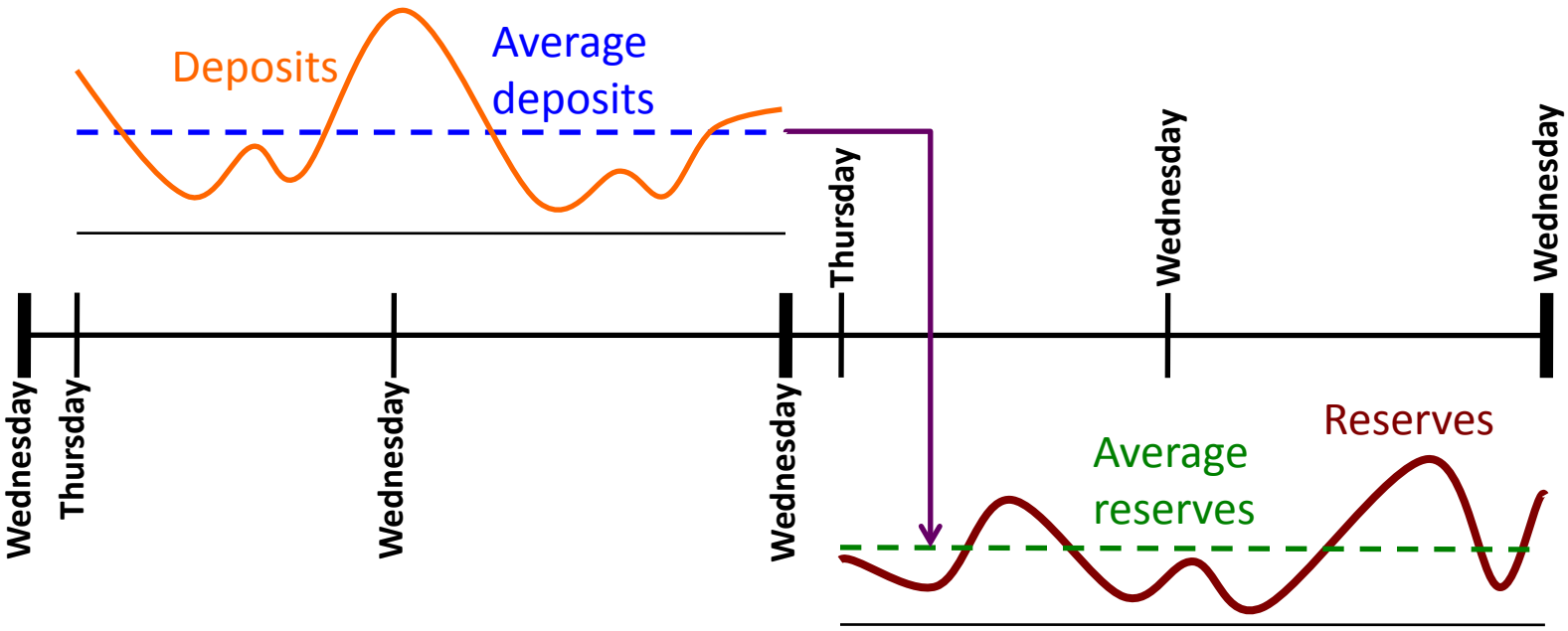
- Banks' reserve balances are calculated as the average over a *maintenance period*.
  - Two weeks in the U.S.
  - One month in Japan and the Euro-area
- This period's required reserves are based on banks' average deposits in the *previous* period.
  - Full-period lag in the U.S. and the Euro-area
  - Half-period lag in Japan

Policy implementation by three central banks

	Fed	ECB	BOJ
Reserve requirements	0 to 10%	2% on short- term, 10% on long term	0.05 to 1.3%
Maintenance period	Two weeks	One month	One month
Reserve accounting	Lagged two weeks	Lagged one month	Lagged two weeks
Standing facilities	Lending, 1/2003; Interest on reserves, 10/2008	Both lending and deposit	Lending, 2001 Deposit, 2008
Open market operations	Daily	Weekly	Daily

Reserve accounting in the US

Average reserves in period 2 ≥
(required reserve ratio) ×
(average deposits in period 1)



Maintenance period 1 **Maintenance period 2**

Some facts about the U.S. reserves market

- Banks' reserve balances are calculated as the average over a two-week *maintenance period*.
- This period's required reserves are based on banks' deposits in the *previous* two weeks.
- Banks' "discount window" borrowing since the mid-1980s (until the financial crisis) has been negligible.
- Banks' holdings of excess reserves are normally small (≤ 3% of total).
- At the biweekly (or lower) frequency, reserve demand is therefore likely to be interest *in*elastic.

Evidence of reserve demand (in)elasticity

(from Table 1 in Friedman-Kuttner *Handbook* chapter)

	1990-2007	1990-1994	1994-2007
Funds rate (t)	−0.083	−0.376	0.011
Funds rate (t–1)	0.077	0.394	−0.018
Reserves (t–1)	0.81***	0.68***	0.86***
Reserves (t–2)	−0.16***	−0.10	−0.19***
Σ of funds rate coeffs	−0.006	0.017	−0.007
Joint significance	0.13	0.25	0.40

Notes: Dependent variable = log of excess reserves. Biweekly data. Robust standard errors. Coefficients on constant and trend are not reported.

Results for the Euro-area

Table 2 Estimates of Excess Reserve Demand for the Euro Area

	June 1999–June 2007		March 2002–June 2007	
	Reserves	**Deposits + reserves**	**Reserves**	**Deposits + reserves**
Intercept	−0.23*** (0.07)	−0.17** (0.07)	−0.30*** (0.09)	−0.29** (0.13)
Main refinancing rate	−0.003 (0.018)	0.054** (0.024)	0.035 (0.032)	0.072 (0.055)
Reserves, lagged 1 period	0.32*** (0.13)	0.42*** (0.09)	0.39*** (0.09)	0.05 (0.11)
January 2002 dummy	0.77*** (0.05)	0.54*** (0.07)		
February 2002 dummy	−0.012 (0.11)	−0.45*** (0.08)		
Number of observations	95	95	62	62
R-squared	0.334	0.327	0.195	0.067

Results for Japan

Table 3 Estimates of Excess Reserve Demand for Japan

Regressor	Sample: Jan 1992–Feb 1999	March 1992–June 2007	January 1992–June 2007	
Intercept	−1.81*** (0.41)	−1.03** (0.43)	−1.19*** (0.41)	−1.71*** (0.42)
Log of call rate	−0.36*** (0.09)	−0.29*** (0.11)	−0.29*** (0.10)	−0.34*** (0.09)
Lagged excess reserves	0.63*** (0.08)	0.67*** (0.12)	0.74*** (0.08)	0.65*** (0.08)
Dummy for zero interest rate policy (ZIRP)				0.83*** (0.32)
Dummy for quantitative easing policy (QEP)				0.65** (0.28)
ZIRP dummy × log of call rate				0.17* (0.09)
Number of observations	86	97	183	183
R-squared	0.710	0.909	0.965	0.968

A simple model of banks' reserve demand within the maintenance period

Begin from a 3-asset model of banks' reserve demand, given total liquidity

$$\begin{pmatrix} R \\ F \\ T \end{pmatrix}_t^d = L[\alpha + \mathbf{Br}] = L\left[\begin{pmatrix} \alpha^R \\ \alpha^F \\ \alpha^T \end{pmatrix} + \begin{pmatrix} \beta^{RR} & -\beta^{RF} & -\beta^{RT} \\ -\beta^{FR} & \beta^{FF} & -\beta^{FT} \\ -\beta^{TR} & -\beta^{TF} & \beta^{TT} \end{pmatrix}\begin{pmatrix} r^R \\ r^F \\ r^T \end{pmatrix}_t + \begin{pmatrix} e_t^R \\ e_t^F \\ e_t^T \end{pmatrix}\right]$$

- Derived assuming fixed bank liquidity positions (*L*), CRRA objective function, normally distributed asset returns.
- βs are functions of the CRRA parameter and asset return covariances.

A simple model of banks' reserve demand within the maintenance period

$$R_t^d = \alpha^R - \beta^{RF} r_t^F - \beta^{RT} r_t^T - \gamma(r_t^F - E_t r_{t+1}^F) + e_t^R$$

- Here demand also responds to *the difference* between today's rate and the expected future rate

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- Here demand also responds to *the difference* between today's rate and the expected future rate
- If the relevant margin is between reserves and fed funds, then $\beta^{RT} = 0$ and

$$R_t^d = \alpha^R - \beta^{RF} r_t^F - \gamma(r_t^F - E_t r_{t+1}^F) + e_t^R$$

A model of the Fed’s reserve supply

A model of the Fed's reserve supply

$$R_t^s = R^* + \lambda\gamma(E_t r_{t+1}^F - \bar{r}_t^F) + u_t^R$$

- The Fed's Open Market Desk reacts to *expected* deviations of the funds rate from its target.
- λ parameterizes the Desk's response: λ= 1 => deviations are fully offset.

The market-clearing rate

The market-clearing rate

$$r_t^F = \frac{\beta^{RF} + \lambda\gamma}{\beta^{RF} + \gamma}\bar{r}^F + \frac{(1-\lambda)\gamma}{\beta^{RF} + \gamma}E_t r_{t+1}^F + \frac{1}{\beta^{RF} + \gamma}(e_t^R - u_t^R)$$

- "Anticipation effect": The market-clearing interest rate is a convex combination of the target rate and the expected rate.

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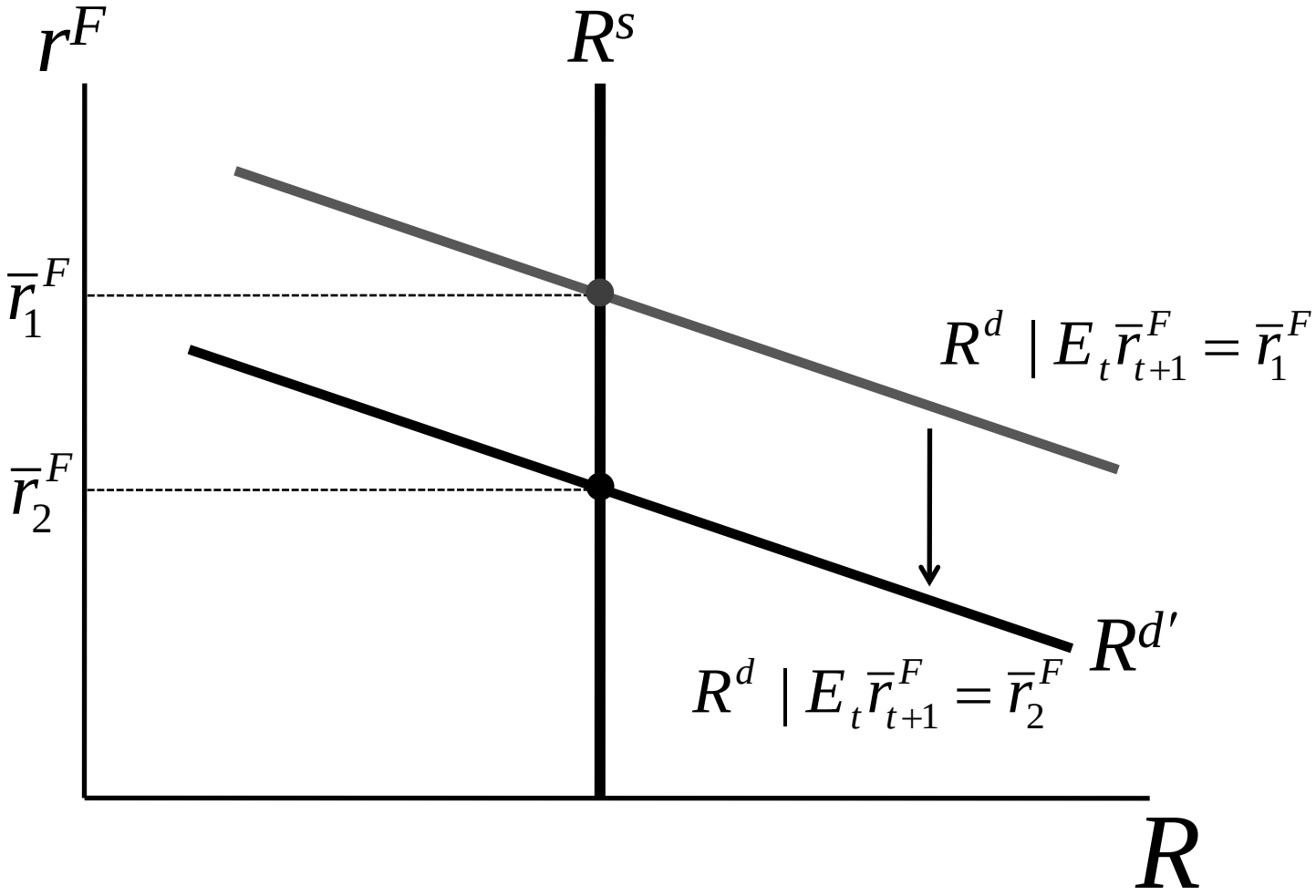
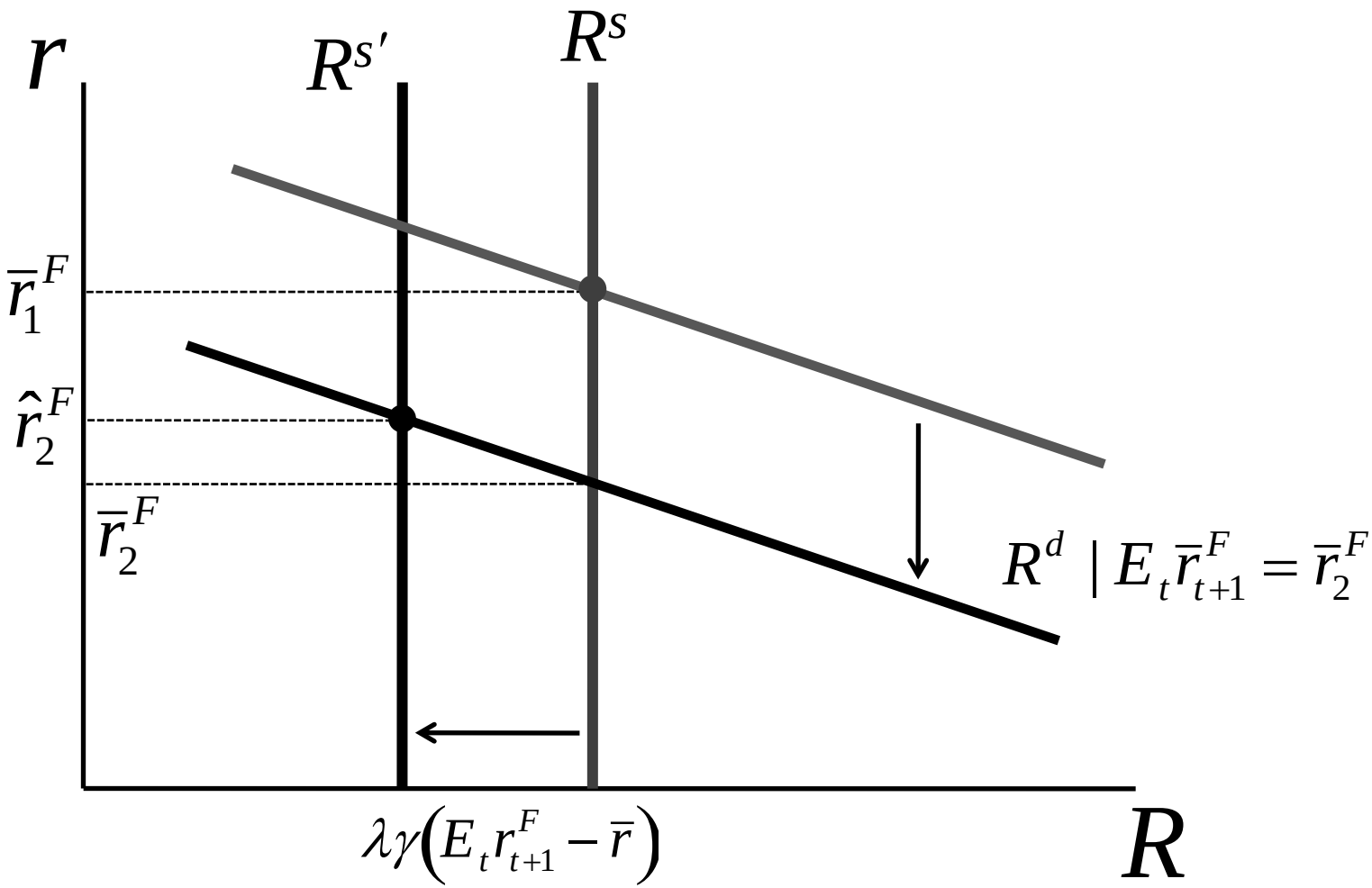
- "Anticipation effect": The market-clearing interest rate is a convex combination of the target rate and the expected rate.
- "Announcement effect": If $\beta^{RF} = 0$, then

$$E_{t+1} r_{t+1}^F = \bar{r}^F \Rightarrow r_t^F = \bar{r}^F$$

A credible, announced rate cut



Demand *and* supply reactions to an expected *future* rate cut



Important implications

- If the interest elasticity of reserve demand is zero, *expectations alone* will move the funds rate: the "announcement effect."
- Expected *future* rate changes within the maintenance period will affect *today's* funds rate, if $\lambda < 1$: the "anticipation effect."

Does the evidence support this model?

- Estimate daily reserve demand and supply regressions in order to:
  - Confirm the small size of the liquidity effect
  - Determine whether reserve demand depends on the *level* of the funds rate…
  - …as opposed to the *expected change* in the funds rate.
  - Assess the Fed's supply response to deviations of the funds rate from its target.

Estimating daily reserve demand

- Invert the demand equation to express the market-to-target funds rate *spread* as a function of the level of reserves.
  - Problem: many reserve demand shocks are foreseen by the Fed, which adjusts reserves accordingly.
  - Solution: following Hamilton, use the reserves "miss" as an instrument for *R*.
  - The "miss" is a good instrument for *R*, regardless of whether a liquidity effect exists.
- Include other control variables and lags.

The resulting (daily) reserve demand regression

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$$r_t^F - \bar{r}_t^F = \theta_1^d \bar{r}_t^F + \theta_2^d R_t + \theta_3^d R_{t-1}^X + \sum \varphi_j^d d_{jt} \Delta^e \bar{r}_t^F +$$

$$\text{lagged } (r^F - \bar{r}^F) \text{ terms and calendar effects}$$

where $\theta_1^d = \gamma^{-1}\beta^{RF}$ and $\theta_2^d = \gamma^{-1}$

- Reserve data are from the Fed, expected funds rates are calculated from futures data.
- Daily data, 1/26/1994 to 7/2/2007: 3468 daily observations (excluding Y2K & 9/11).

Daily reserve demand results

(from Table 5 in Friedman-Kuttner *Handbook* chapter)

Estimated response of the effective-to-target funds rate spread to:	
The expected funds rate change on	
Day 1 of maintenance period	**0.31*** **
Day 2 of maintenance period	**0.30*** **
Day 3 of maintenance period	**0.14*** **
Day 4 of maintenance period	**0.13*** **
Days 5+	**≈ 0**
Day *t* excess reserves	**–0.92*** **
Cumulative excess reserves	**–0.59*** **
Target federal funds rate	**0.004**

Notes: daily data, 1/26/1994 to 7/2/2007, weighted 2SLS with the reserves "miss" as the instrument for excess reserves. Coefficients on calendar effects, lagged dependent variable, and no-FOMC-meeting expected changes are not reported.

Daily reserve *supply* regressions

Daily reserve *supply* regressions

- Start with the reserve supply equation.
- Include other control variables and lags.
- Use “intended” supply: the actual level of reserves minus the ex-post-observable supply “miss.”

Daily reserve *supply* regressions

- Start with the reserve supply equation.
- Include other control variables and lags.
- Use "intended" supply: the actual level of reserves minus the ex-post-observable supply "miss."

$$\tilde{R}_t^s = \theta_1^s R_{t-1}^X + \theta_2^s \Delta \bar{r}_t^F + \theta_3^s \Delta_p \bar{r}_t^F + \theta_4^s \bar{r}_t^F + \varphi^s (E_{t-1} r_t^F - \bar{r}_t^F) +$$

$$\text{lagged } \tilde{R}^s \text{ terms and calendar effects}$$

where $\varphi^{\mathrm{s}} = \lambda\gamma$

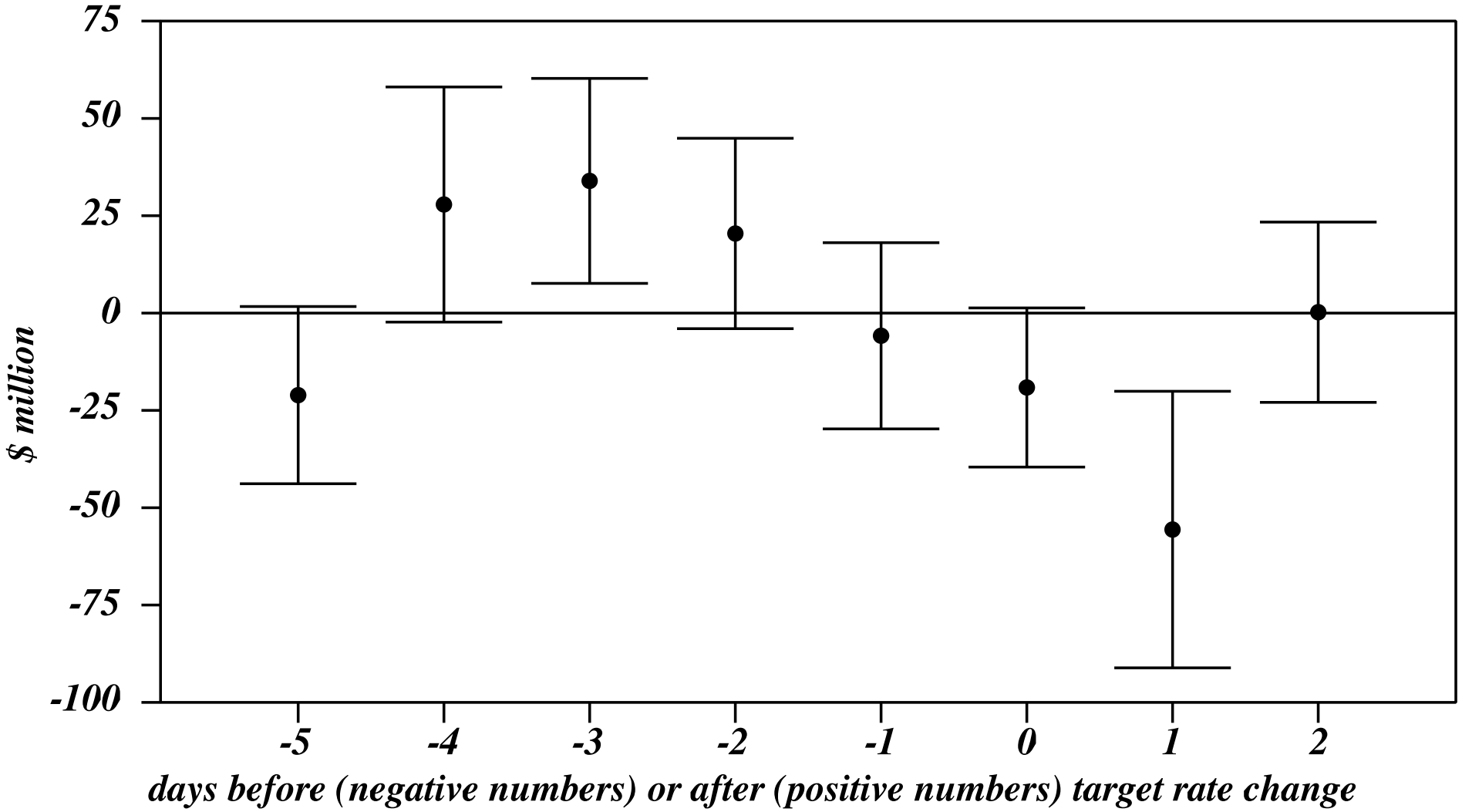
Daily reserve supply results

(from Table 6 in Friedman-Kuttner *Handbook* chapter)

Estimated response of excess reserves to:	
Cumulative excess reserves	**−0.382*** **
Target federal funds rate	**−0.021**
Change in the target federal funds rate	**0.004**
Funds rate change on preceding days of MP	**−0.016*** **
Expected deviation of funds rate from target	**0.049*** **

Notes: daily data, 1/26/1994 to 7/2/2007, weighted 2SLS with instruments for the target rate change and the expected deviation constructed from fed funds futures data. Coefficients on calendar effects and lagged dependent variables are not reported.

Within the maintenance period, reserves *rise* in anticipation of rate hikes

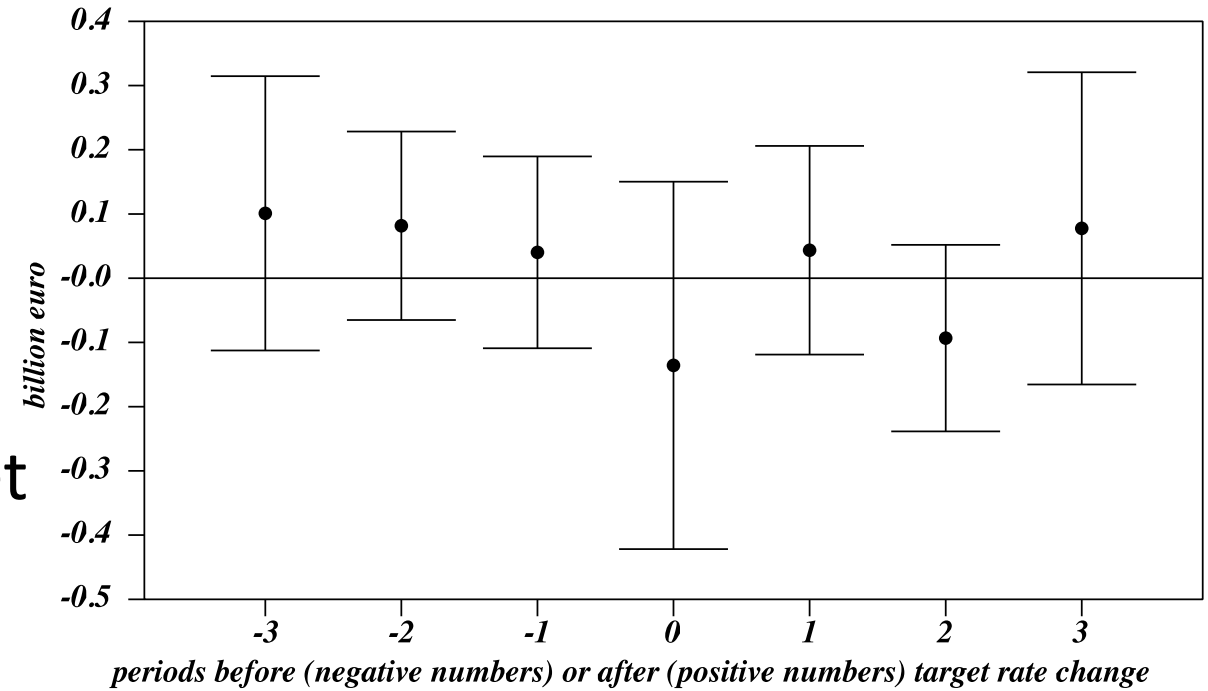


Summary of results for estimation of U.S. reserve demand and reserve supply

- The daily "liquidity effect" is indeed very small.
- Reserve demand does *not* depend on the *level* of the funds rate.
- Reserve demand *is* highly sensitive to *expected changes* in the rate.
- Changes in *r* are *not* systematically associated with discernable changes in *R*.
- The Fed partially offsets deviations from the target by varying reserve supply.

Does the "new view" apply to the ECB?

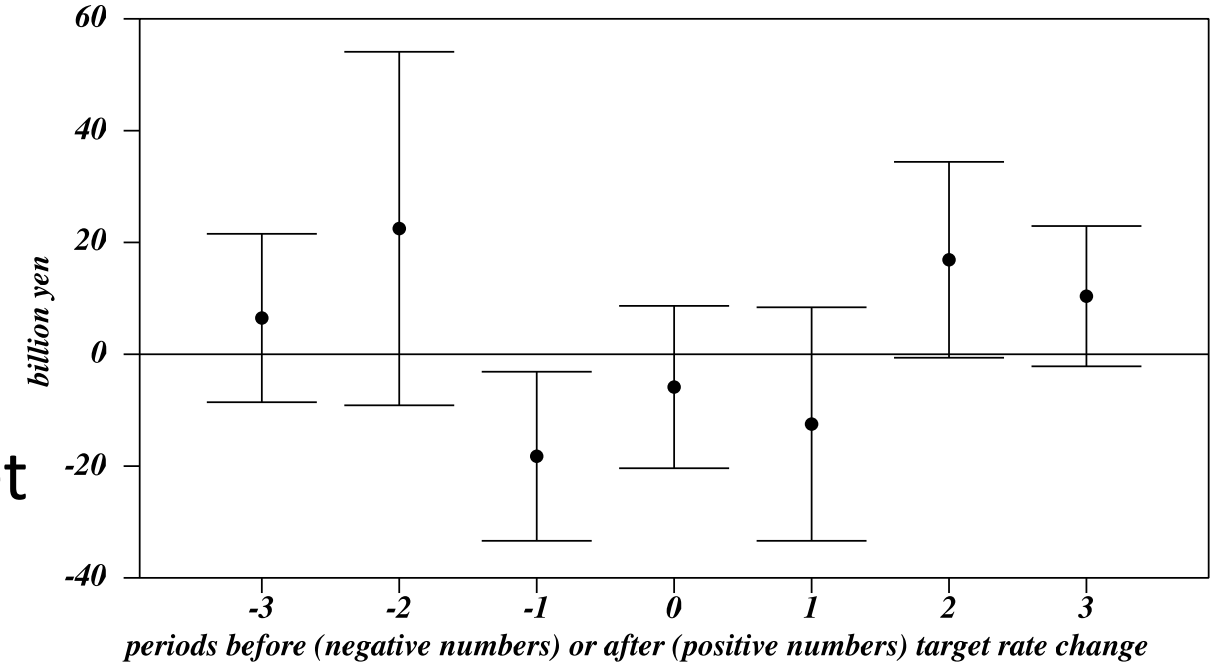
- **Yes.**
- No reserve movements accompany target rate changes.



- Recall: reserve demand is inelastic.
- Borrowing/lending "corridor" helps stabilize EONIA rate around target, despite infrequent open market operations.

Does the "new view" apply to the BOJ?

- **Partially.**
- *Small* reserve movements accompany target rate changes.

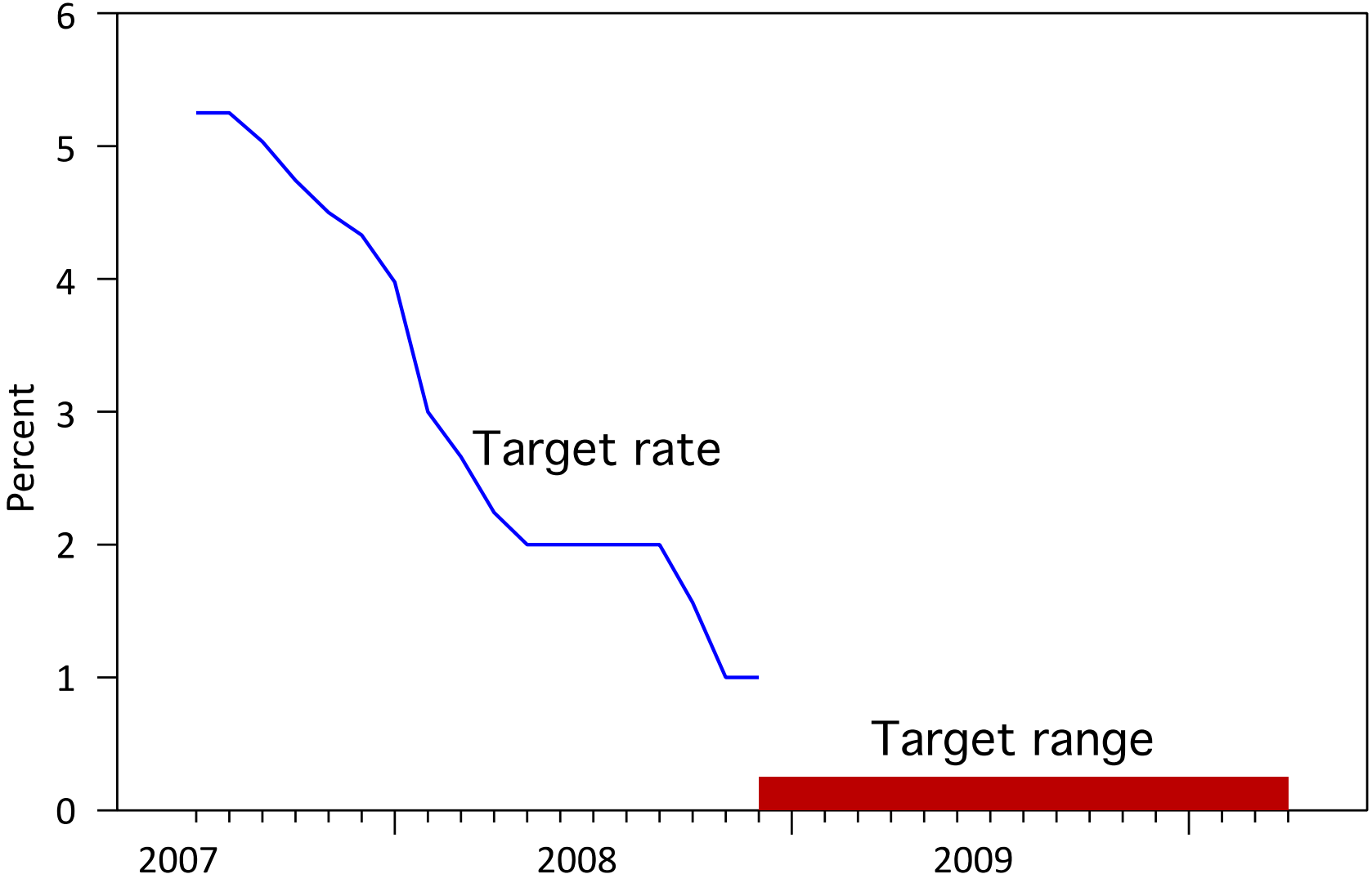


- Recall: there *is* some evidence of a nonzero interest elasticity of reserve demand in Japan — especially as the overnight rate approached zero.

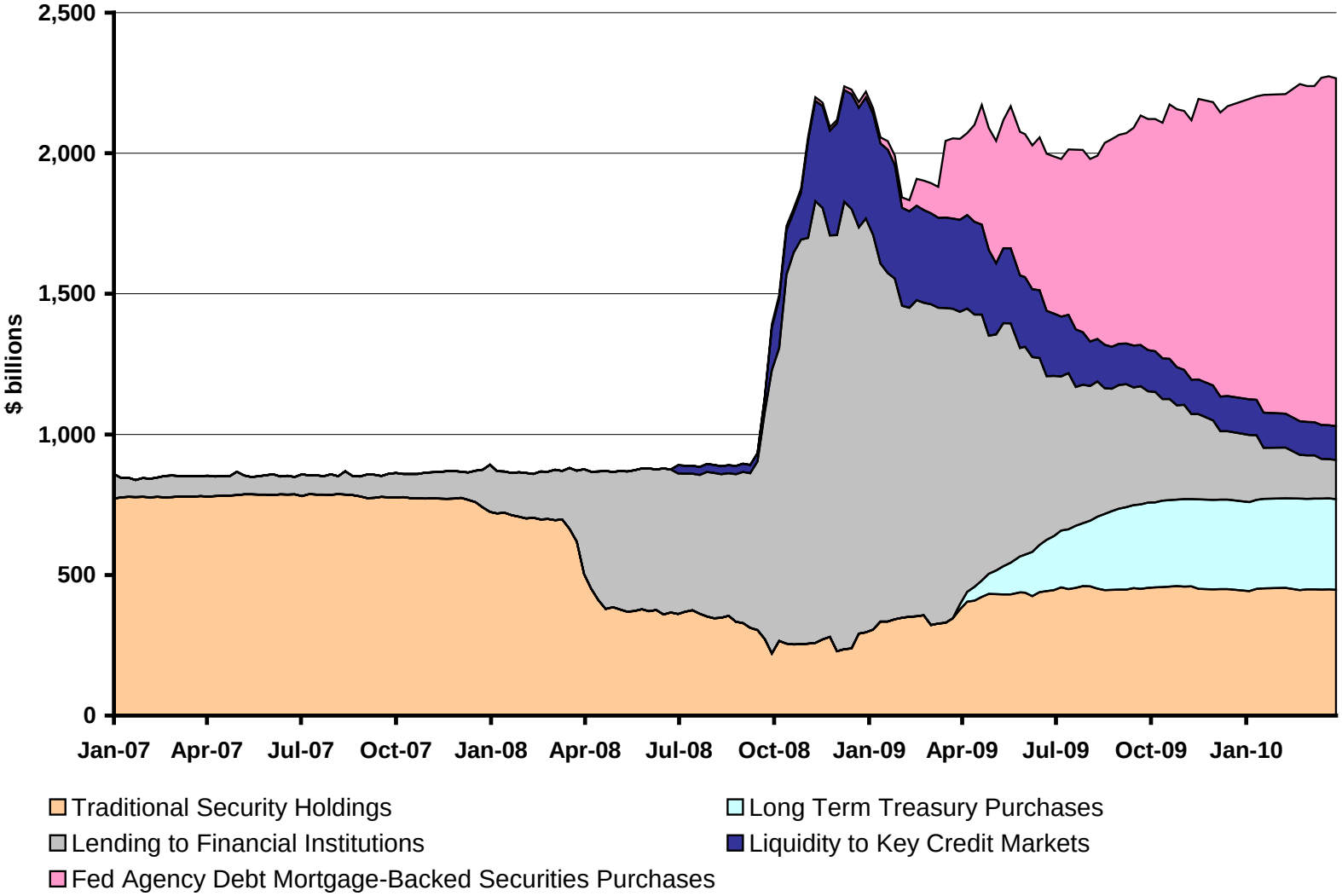
Questions from the crisis (1)

- Recall the large expansion of central bank balance sheets: from “quantitative easing” once the policy interest rate reached the zero lower bound

Monetary policy at the zero lower bound in the U.S.

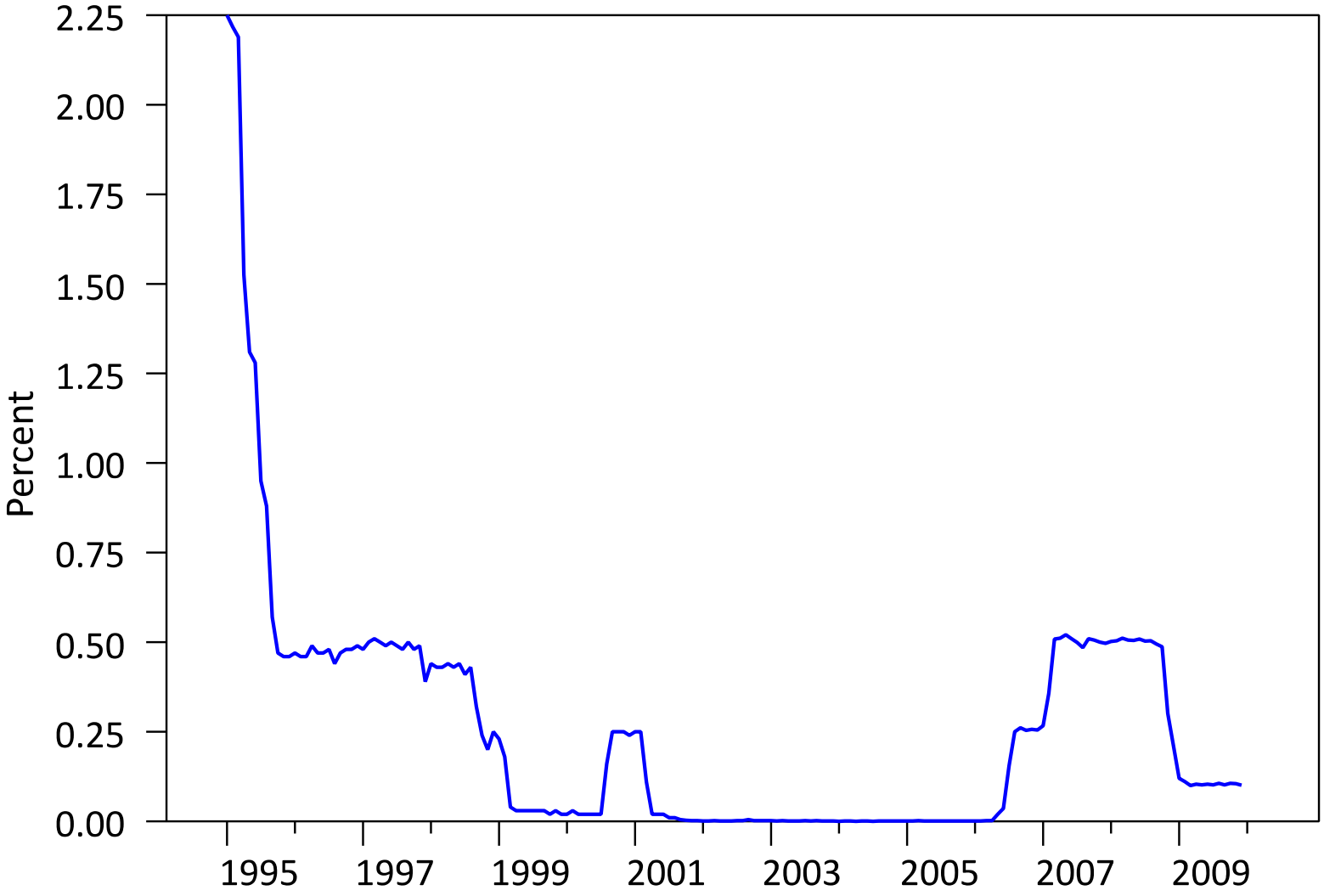


Federal Reserve Balance Sheet

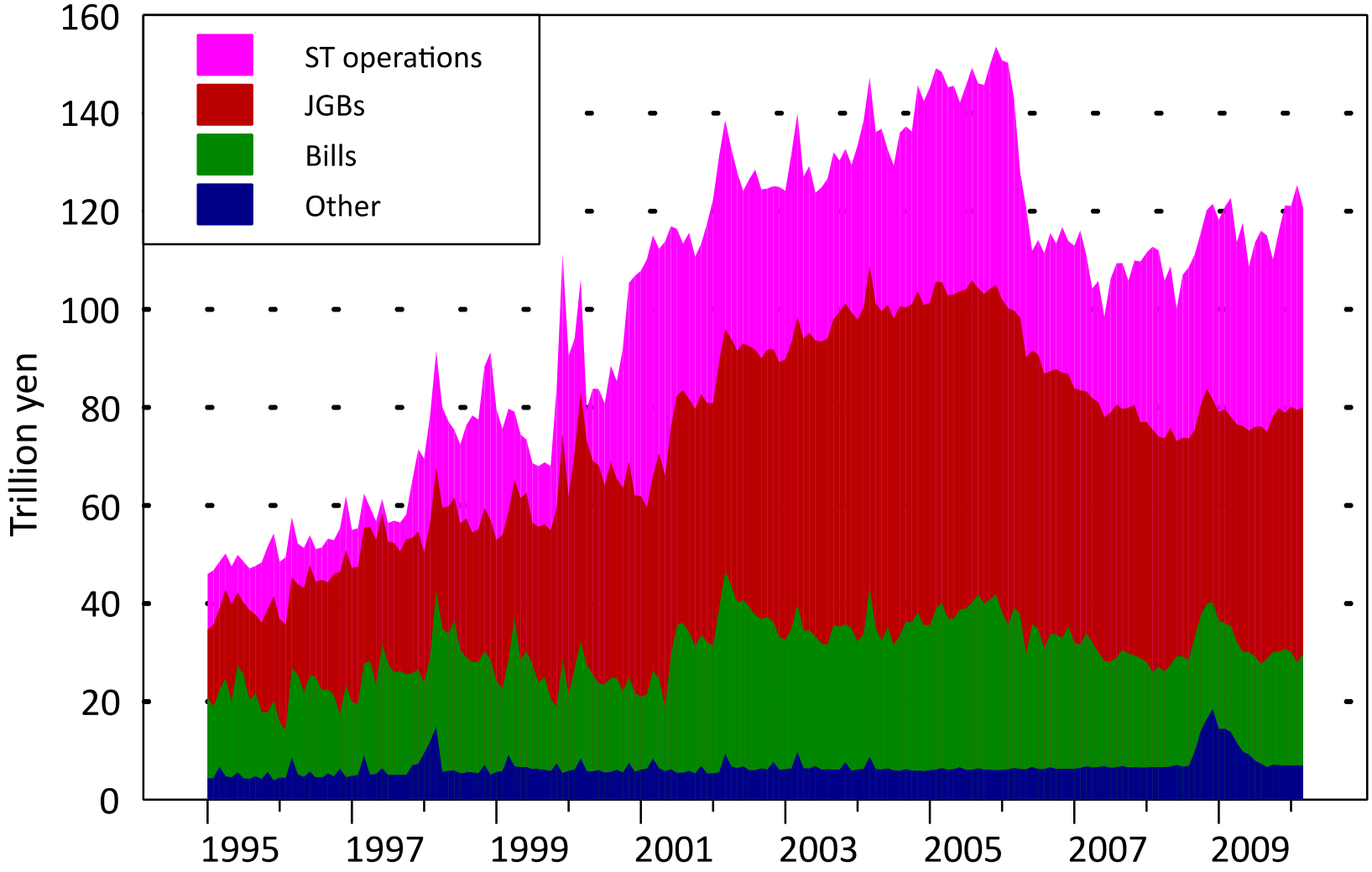


Source: Federal Reserve Bank of Cleveland

Monetary policy at the zero lower bound in Japan

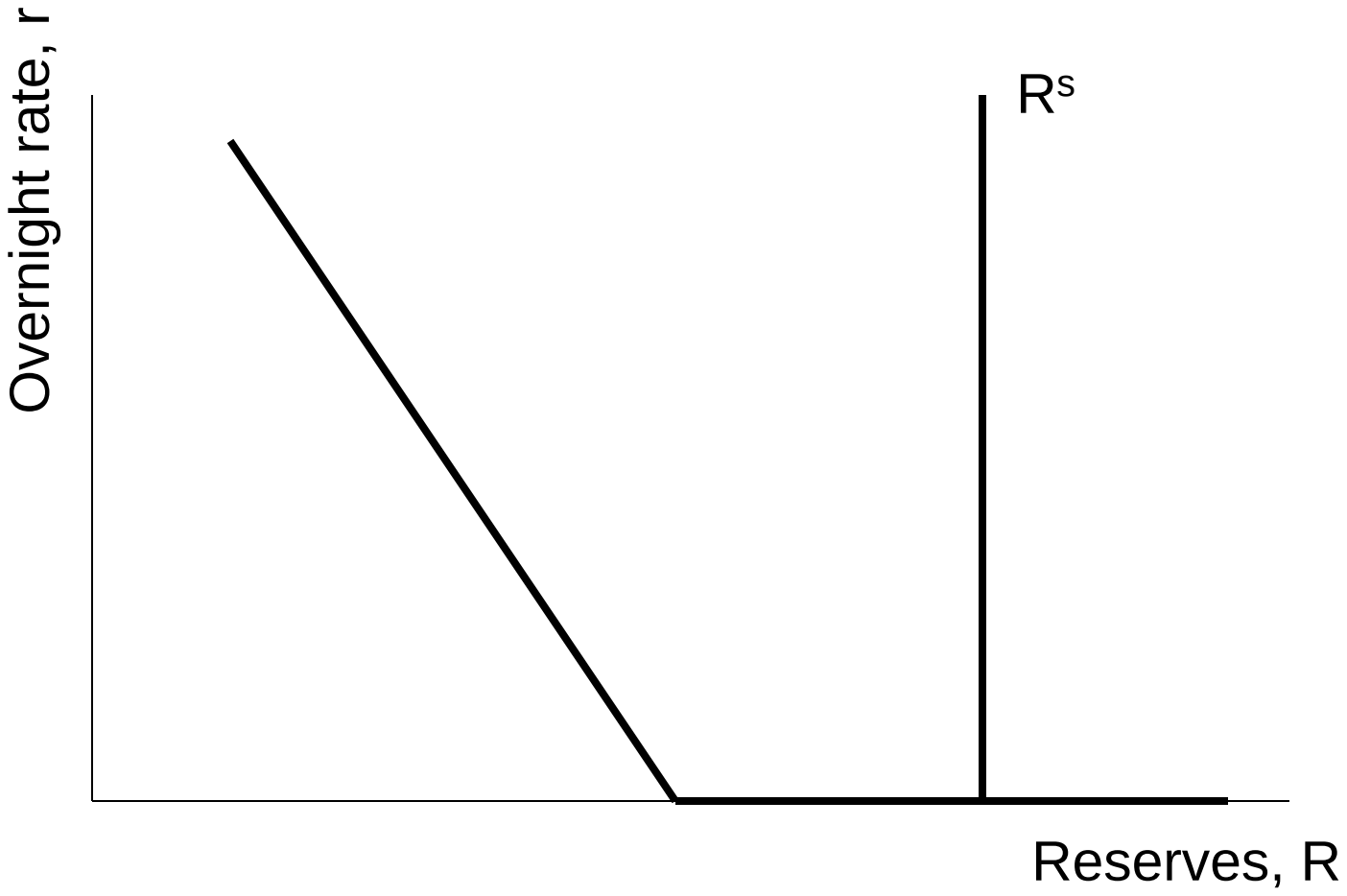


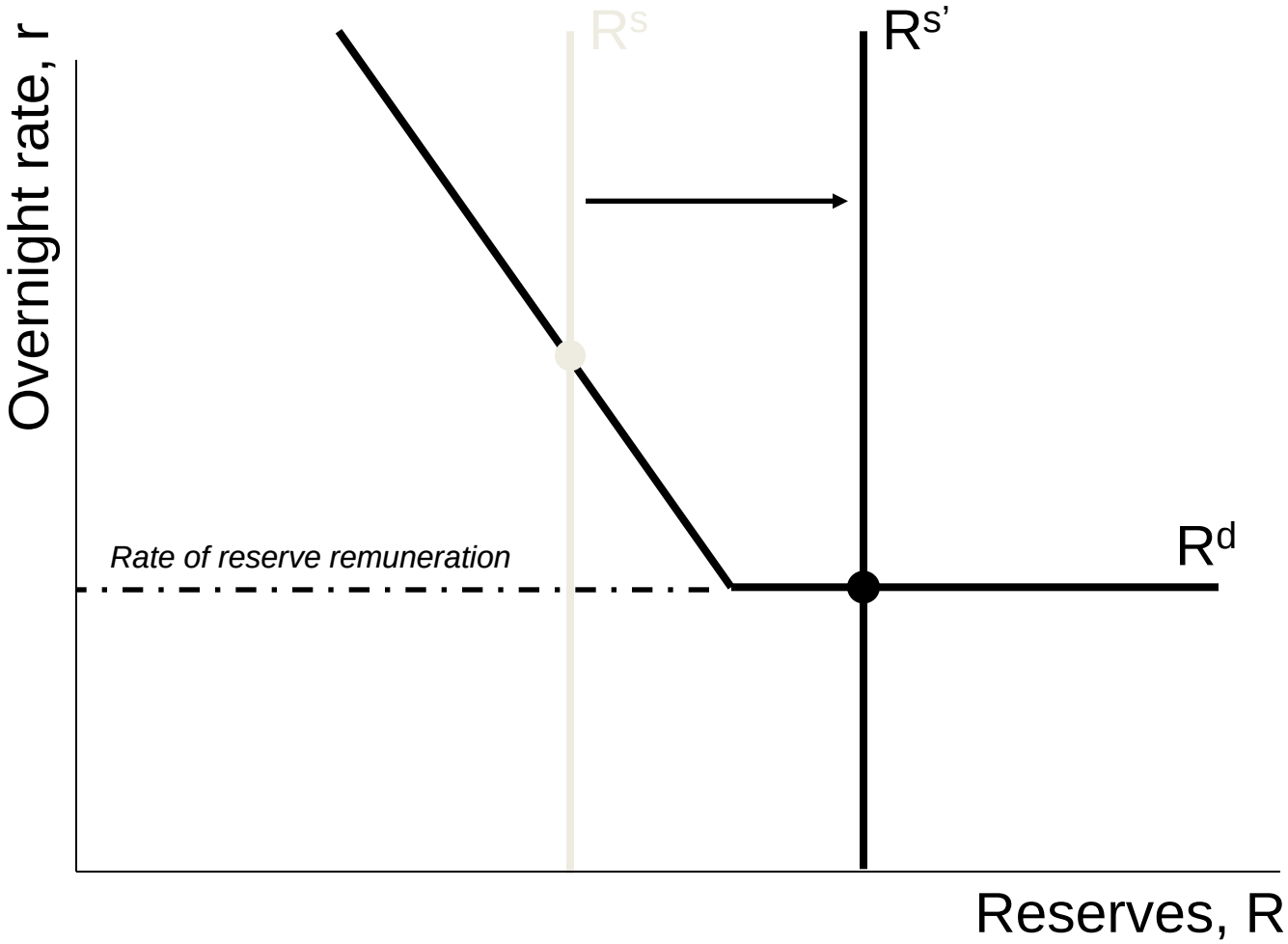
Bank of Japan balance sheet



Questions from the crisis (1)

- Recall the large expansion of central bank balance sheets: from “quantitative easing” once the policy interest rate reached the zero lower bound
- Do central banks have to “unwind” these positions before they begin to raise interest rates (whenever the time comes to do that)?
- No!
- Reason: the ability to use the rate paid on excess reserve holdings as a floor under the market rate

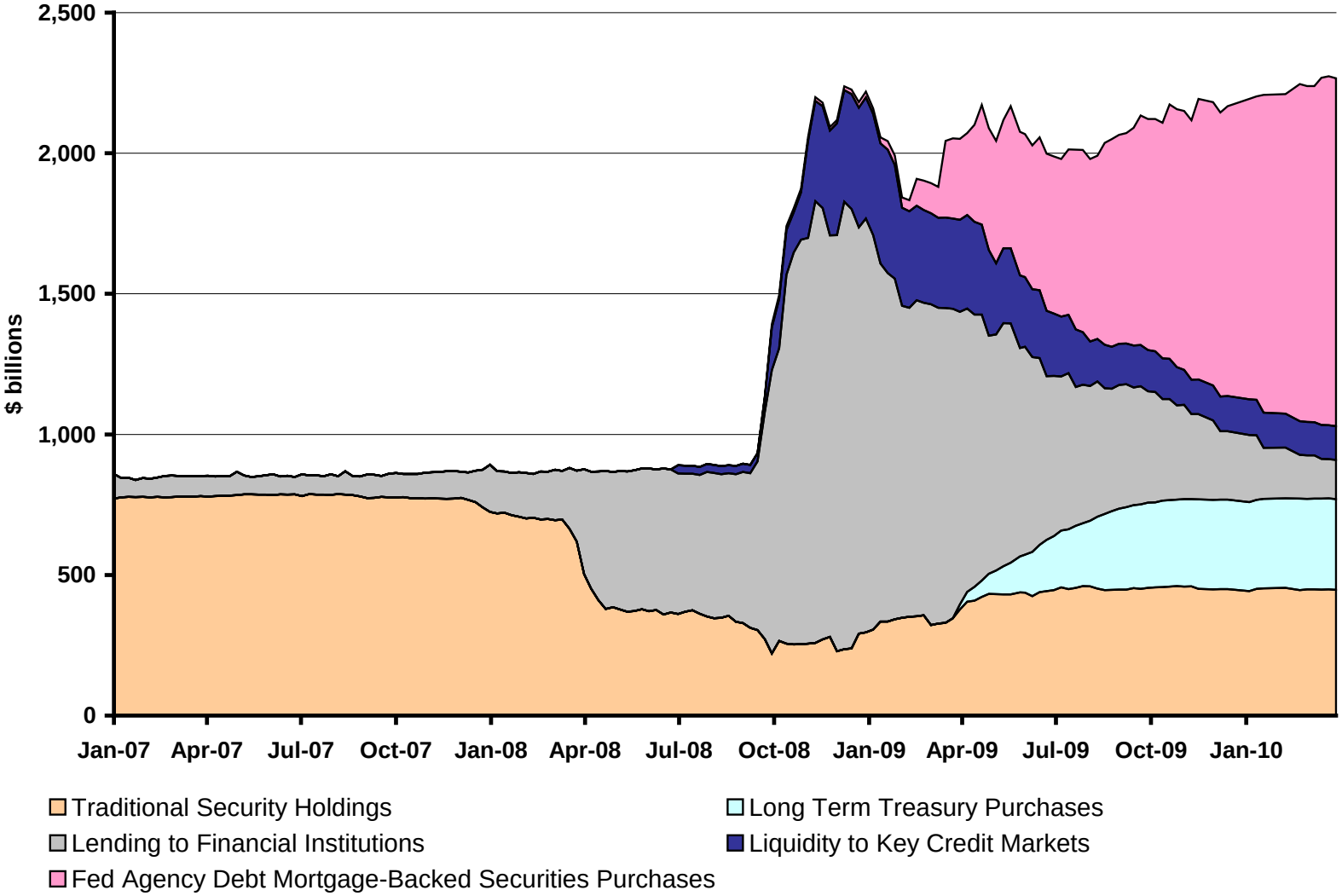

Overnight rate, r
R^s
Reserves, R


Overnight rate, r
R^s
$R^{s'}$
Rate of reserve remuneration
R^d
Reserves, R

Questions from the crisis (2)

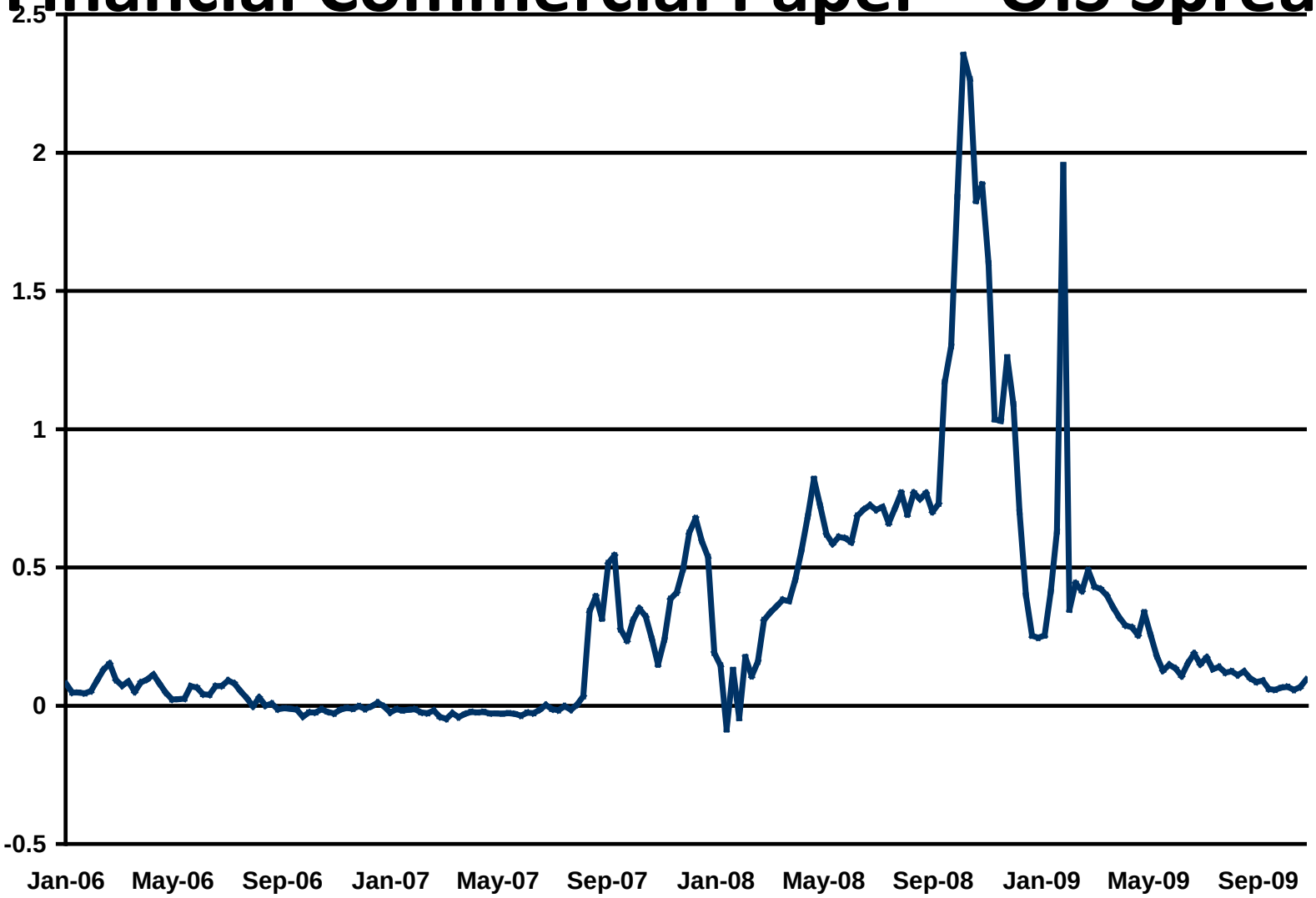
- Did quantitative easing work?
- Distinguish two issues:
  - Pure quantity effects (*size* of the central bank's balance sheet)
  - Security selection effects (*composition* of the balance sheet)
- U.S.: substantial evidence of composition effects

Federal Reserve Balance Sheet



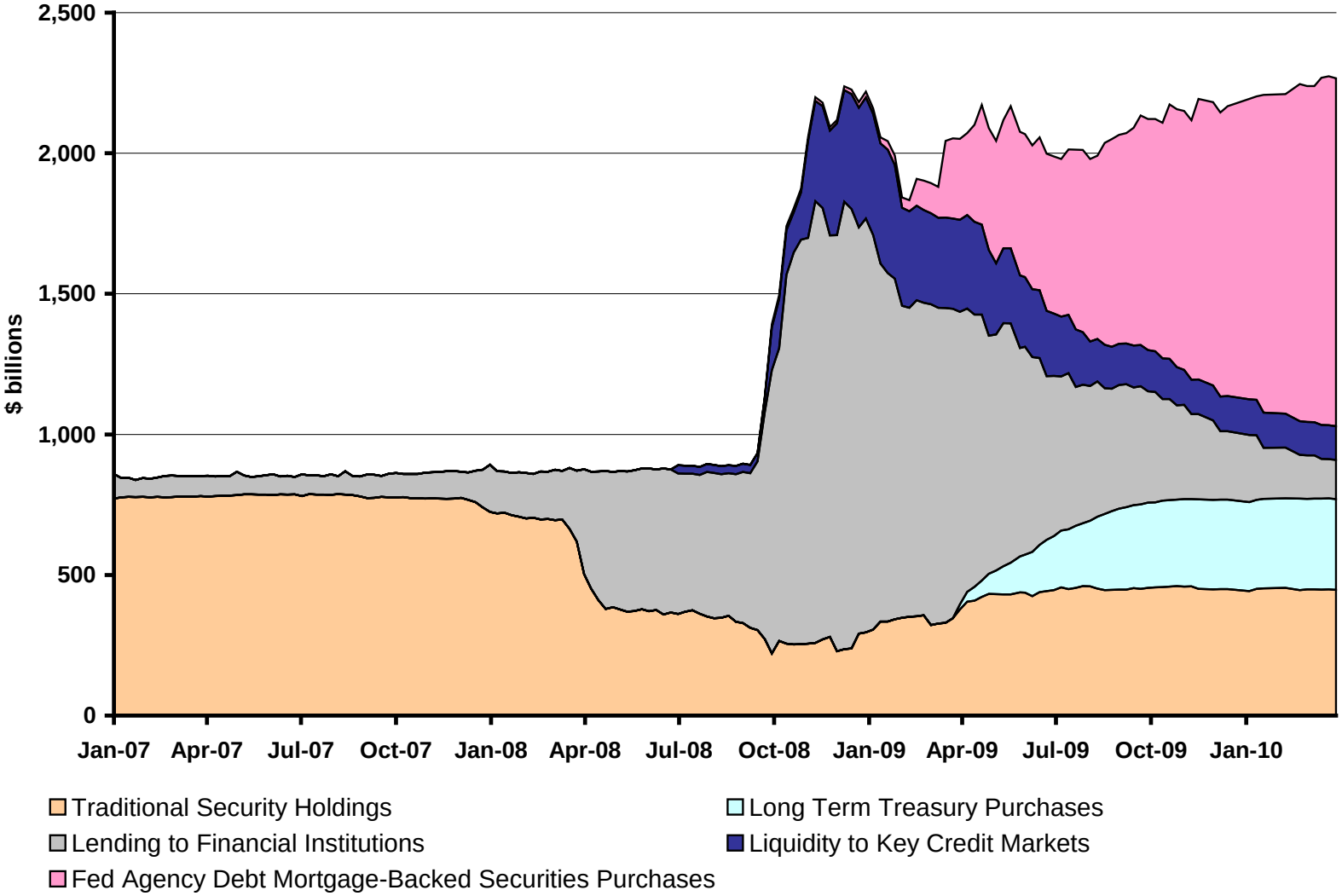
Source: Federal Reserve Bank of Cleveland

Financial Commercial Paper – OIS Spread



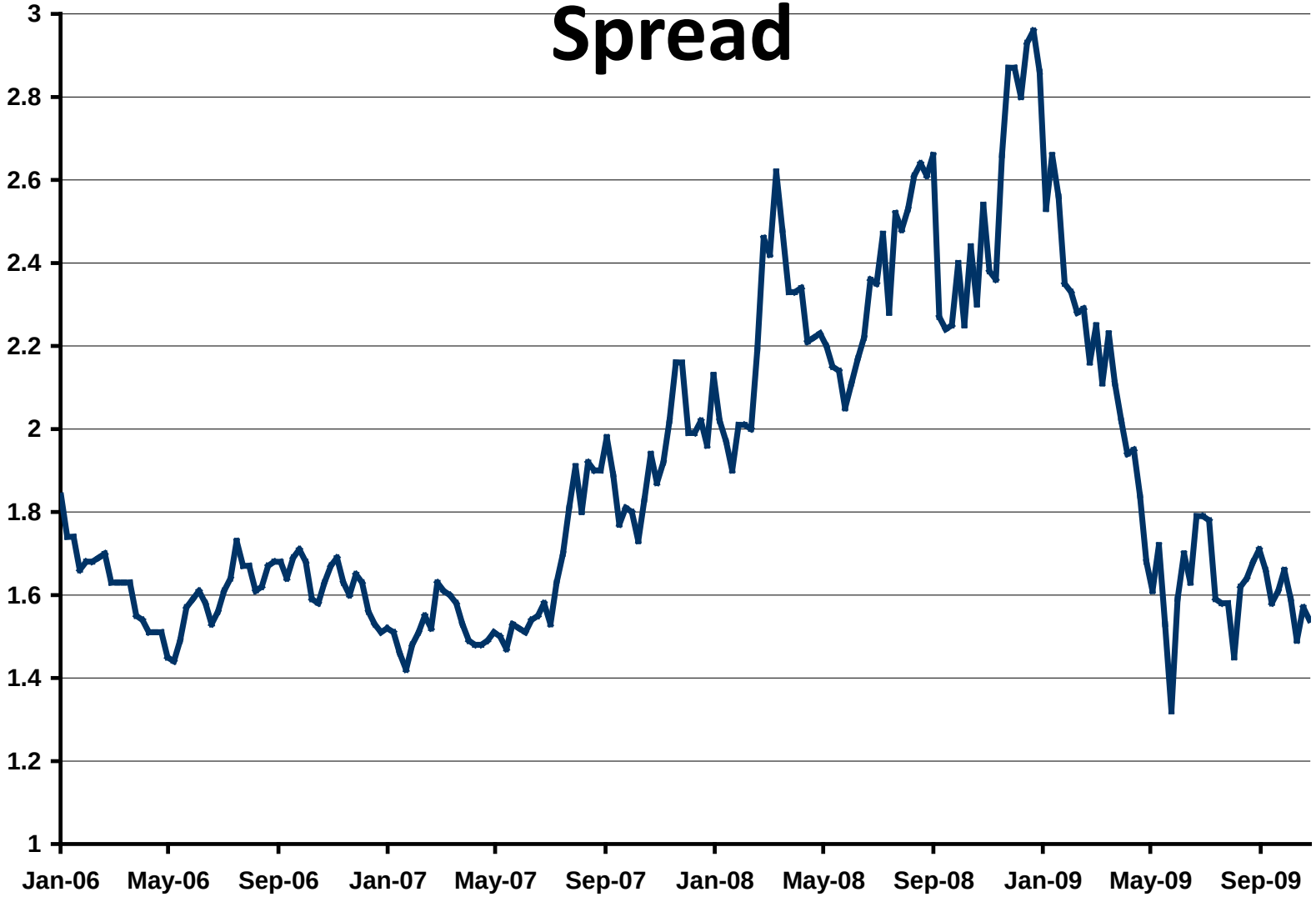
Source: Federal Reserve Statistical Release H.15, Bloomberg Professional

Federal Reserve Balance Sheet



Source: Federal Reserve Bank of Cleveland

30-year Mortgage – 10-year T-Bill Spread



Source: Federal Reserve Board Statistical Release H.15

Questions from the crisis (2)

- Did quantitative easing work?
- Distinguish two issues:
  - Pure quantity effects (*size* of the central bank's balance sheet)
  - Security selection effects (*composition* of the balance sheet)
- U.S.: substantial evidence of composition effects
- By contrast, little evidence of pure size effects
  - Hence doubts about the effectiveness of the Fed's "QE2"
- Is there comparable evidence for Japan?

Overall conclusions (1)

- Money & banking and macro textbooks (and our everyday understanding) need some major revisions.
  - Central banks' day-to-day implementation of monetary policy relies on announcements and expectations, not changes in reserves.
  - Over longer horizons, reserve-bearing monetary quantities presumably respond endogenously to interest rate changes.
  - But this requires a broader analysis of the impact of interest rates on deposit and loan markets.

Overall conclusions (2)

- Central banks' recent "quantitative" actions have further challenged conventional views on the links between prices and quantities.
  - With interest paid on reserves, the interest rate and the quantity of reserves are potentially two independent policy instruments.
  - Hence central banks need not "unwind" their asset purchases in order to raise rates.
  - Whether they should retain their asset positions, when the time comes to raise rates, is a separate question: the potential impact on interest rate *relationships* from asset *composition* effects.

Overall conclusions (3)

- The most fundamental question
  - The *general interest rate level* affects economic activity; but the central bank can influence that interest rate level without implications from the size of its balance sheet.
  - *Interest rate relationships* also affect economic activity; and the central bank can influence them too without implications from the size of its balance sheet.

Overall conclusions (3, cont.)

- But does the size of the central bank's balance sheet *per se* matter for economic activity?
- Does it even matter for inflation?
- If not, is that the end of the classical quantity theory?