Turnover Liquidity and the Transmission of Monetary Policy

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Two questions

- What is the effect of monetary policy on the stock market?
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- What is the effect of monetary policy on the stock market?

- What is the mechanism?
What we do

Theory
- Develop a model of monetary exchange in financial markets
- Study the effects of monetary policy on returns and financial liquidity

Evidence
Estimate the impact of monetary policy on returns and turnover:
- Marketwide
- Across stocks with different liquidity

Quantitative Theory
- Calibrate and simulate model to quantify the theoretical mechanism
Theoretical results

Show how the quantity of money and market microstructure:
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1. Determine asset prices and standard measures of financial liquidity
   (trade volume, dealer supply of immediacy, spreads)
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   tight money increases opportunity cost of holding nominal assets
   routinely used to settle financial transactions (money, bank reserves)

   ⇒ nominal assets become scarcer
   ⇒ reduced resalability of stocks
   ⇒ stock turnover falls
   ⇒ stock price falls
Empirical findings

↓ 25 bp surprise increase in policy rate ⇒ fall in marketwide...
Empirical findings

- 25 bp surprise increase in policy rate $\Rightarrow$ fall in marketwide...
  - Stock return (between 1% and 2%)
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1. **25 bp surprise increase in policy rate** $\Rightarrow$ **fall in marketwide**...
   - **Stock return** (between 1% and 2%)
   - **Turnover rate** (between 17% and 30%)
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   - Return and turnover fall for all stock classes, but...
     - ... relative to the class of stocks with median liquidity:
       - Return of top 5% most liquid falls 2 times more
       - Turnover of top 5% most liquid falls 2-3 times more
Quantitative results

A calibrated version of the model accounts for:

1. Sign and 26% to 60% of the response of stock returns
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2. Sign, persistence, modest part of initial response of turnover
Quantitative results

A calibrated version of the model accounts for:

1. Sign and 26% to 60% of the response of stock returns

2. Sign, persistence, modest part of initial response of turnover

3. Relative magnitude of responses of returns and turnover across liquidity classes
Inflation, liquidity, and asset prices


Money in OTC financial markets


Speculative bubbles

Monetary policy and asset prices: related empirical work

**Event-study methodology**


**High-frequency identification**


**Heteroskedasticity-based identification**

Rigobon and Sack (2004)

**Role of firm characteristics**

Environment

- *Time*. Discrete, infinite horizon, two subperiods per period

- *Population*. [0, 1] investors (infinitely lived)

- *Commodities*. Two divisible, nonstorable consumption goods:
  - *dividend good*
  - *general good*
Preferences

\[ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (\varepsilon_t y_t + c_t - h_t) \]

- \( \beta \in (0, 1) \): discount factor
- \( c_t \): consumption of general good
- \( h_t \): effort to produce general good
- \( y_t \): consumption of dividend good
- \( \varepsilon_t \): valuation shock, i.i.d. over time, cdf \( G(\cdot) \) on \( [\varepsilon_L, \varepsilon_H] \)
Endowments and production technology

**First subperiod**

$A^s$ productive units (*trees*)

- Each unit yields $y_t$ dividend goods *at the end of the first subperiod*  
  $y_t = \gamma_t y_{t-1}$, where $\gamma_t \sim \text{i.i.d.}$ with $\mathbb{E}(\gamma_t) = \bar{\gamma}$

- Each unit permanently “fails” with probability $1 - \delta$ at the beginning of the period

- Failed units immediately replaced by new units (allocated uniformly to investors)

**Second subperiod**

- Linear technology to transform effort into general goods
Assets

Equity shares

- $A^s$ equity shares

- At the beginning of period $t$:
  - $(1 - \delta) A^s$ shares of failed trees disappear
  - $(1 - \delta) A^s$ shares of new trees allocated uniformly to investors

Fiat money

- Money supply: $A^m_t$ dollars

- Monetary policy: $A^m_{t+1} = \mu A^m_t$, $\mu \in \mathbb{R}_{++}$
  (implemented with lump-sum injections/withdrawals)
Market structure

First subperiod: OTC market

- Money, equity (*cum dividend*)
- Random access to a Walrasian market (with probability $\alpha$)

Second subperiod: centralized market

- Money, equity (*ex dividend*), general good
- Walrasian trade between all agents

“Anonymity” $\Rightarrow$ *quid pro quo* $\Rightarrow$ money used to pay for assets
Timeline and market structure

- Depreciation shock
- Asset endowment
- Dividend is known
- Preference shock

Dividend consumption

Money injection

Investor  Dealer  Dealer  Investor

Interdealer Market

Investor  Dealer  Dealer  Investor

Centralized Market

Period $t$
Value functions

$$W_t^l (a_t) = \max_{c_t, h_t, \tilde{a}_{t+1}} \left[ c_t - h_t + \beta \int V_{t+1}^l (a_{t+1}, \epsilon') \, dG(\epsilon') \right]$$

$$a_{t+1} = (\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s + (1 - \delta) A^s)$$

$$c_t + \phi_t \tilde{a}_{t+1} \leq h_t + \phi_t a_t + T_t$$

$$\phi_t = (\phi_t^m, \phi_t^s) : \text{real prices of money and stock}$$
Value functions

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\[ \phi_t = (\phi_t^m, \phi_t^s) : \text{real prices of money and stock} \]

\[ V_t^l (a_t, \epsilon) = \alpha \left\{ \epsilon y_t \bar{a}_t^s (a_t, \epsilon) + W_t^l [\bar{a}_t (a_t, \epsilon)] \right\} + (1 - \alpha) \left[ \epsilon y_t a_t^s + W_t^l (a_t) \right] \]
Portfolio problem in OTCM

Investor with portfolio $a_t = (a^m_t, a^s_t)$ and valuation $\varepsilon$ solves

$$\max_{\bar{a}_t} \left[ \varepsilon y_t a^s_t + W^l_t (\bar{a}_t) \right]$$

$$\bar{a}^m_t + p_t \bar{a}^s_t \leq a^m_t + p_t a^s_t$$

$p_t$ : nominal equity price in the OTC interdealer market
OTCM post trade portfolio

\[ \overline{a}_t^s = \begin{cases} a_t^s + \frac{1}{p_t} a_t^m & \text{if } \varepsilon_t^* < \varepsilon \\ 0 & \text{if } \varepsilon < \varepsilon_t^* \end{cases} \]

\[ \overline{a}_t^m = \begin{cases} 0 & \text{if } \varepsilon_t^* < \varepsilon \\ a_t^m + p_t a_t^s & \text{if } \varepsilon < \varepsilon_t^* \end{cases} \]

where

\[ \varepsilon_t^* \equiv \frac{p_t \phi_t^m - \phi_t^s}{y_t} \]
Euler equations

\[ \phi_t^m \geq \beta \mathbb{E}_t \left[ \phi_{t+1}^m + \alpha \theta \int_{\varepsilon_{t+1}}^{\varepsilon_t} \left( \frac{\varepsilon y_{t+1} + \phi_{t+1}^s}{p_{t+1}} - \phi_{t+1}^m \right) dG(\varepsilon) \right] \]
Euler equations

\[ \phi_t^m \geq \beta \mathbb{E}_t \left[ \phi_{t+1}^m + \alpha \theta \int_{\varepsilon_{t+1}}^{\varepsilon_H} \left( \frac{\varepsilon y_{t+1} + \phi_{t+1}^s}{p_{t+1}} - \phi_{t+1}^m \right) dG(\varepsilon) \right] \]

\[ \phi_t^s \geq \beta \delta \mathbb{E}_t \left[ \bar{\varepsilon} y_{t+1} + \phi_{t+1}^s \right. \]

\[ \left. + \alpha \theta \int_{\varepsilon_L}^{\varepsilon_{t+1}} \left[ p_{t+1} \phi_{t+1}^m - (\varepsilon y_{t+1} + \phi_{t+1}^s) \right] dG(\varepsilon) \right] \]
Friedman rule

**Proposition**

The allocation implemented by the stationary monetary equilibrium converges to the symmetric efficient allocation as \( \mu \to \bar{\beta} \equiv \beta \gamma \).
Nonmonetary equilibrium

Proposition

(i) A nonmonetary equilibrium exists for any parametrization.

(ii) In the nonmonetary equilibrium:

- there is no trade in the OTC market
- the equity price is:

\[ \phi_t^s = \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \bar{\varepsilon}y_t. \]
Monetary equilibrium

Proposition

(i) If \( \mu \in (\bar{\beta}, \bar{\mu}) \), there is one stationary monetary equilibrium.

(ii) For any \( \mu \in (\bar{\beta}, \bar{\mu}) \), there exists a unique \( \varepsilon^* \in (\varepsilon_L, \varepsilon_H) \).

(iv) As \( \mu \to \bar{\beta} \), \( \varepsilon^* \to \varepsilon_H \) and \( \phi_t^s \to \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \varepsilon_H y_t \).
Stationary monetary equilibrium: allocations

\[ \phi_t^s = \phi^s y_t \]

\[ \phi^s \equiv \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \left[ \bar{\epsilon} + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) \, dG(\varepsilon) \right] \]

\[ \phi_t^m A_t^m = \frac{\alpha G(\varepsilon^*) A_s}{\alpha \left[ 1 - G(\varepsilon^*) \right]} (\varepsilon^* + \phi^s) y_t \]
Proposition

In the stationary monetary equilibrium: $\partial \phi_s / \partial \mu < 0$

The nominal interest rate is:

$$r = \frac{\mu - \bar{\beta}}{\bar{\beta}}$$
Trade volume and the nominal interest rate

\[ V = \alpha G (\varepsilon^*) A^s \]

**Proposition**

In the stationary monetary equilibrium: \( \partial V / \partial \mu < 0 \)
The turnover-liquidity transmission mechanism

\[ \mathcal{V} = \alpha G(\varepsilon^*) A^s \]

\[ \phi^s = \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \left[ \bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) \, dG(\varepsilon) \right] \]
The turnover-liquidity transmission mechanism

\[ V = \alpha G(\varepsilon^*) A^s \]

\[ \frac{\partial V}{\partial \mu} = \nu \frac{G'(\varepsilon^*)}{G(\varepsilon^*)} \frac{\partial \varepsilon^*}{\partial \mu} < 0 \]

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Preview of empirical work

- **Aggregate announcement-day effects**
  - Event-study regression
  - Estimation based on heteroskedasticity-based identification
  - High-frequency instrumental variable regression

- **Disaggregative announcement-day effects**
  - Regressions on portfolios sorted on turnover liquidity
  - Regression with panel data on individual stocks
  - Regressions on portfolios sorted on liquidity betas

- **Dynamic effects**
  (VAR identified with external high-frequency instrument)
  - VAR with aggregate data
  - VARs on portfolios sorted on turnover liquidity
Data

- **Returns**
  - stock $s$ on day $t$: $R^s_t = \left( \frac{P^s_t + D^s_t}{P^s_{t-1}} - 1 \right) \times 100$
  - aggregate: $R^l_t = \frac{1}{n} \sum_{s=1}^{n} R^s_t$

- **Volume**
  - turnover rate for stock $s$ on day $t$: $T^s_t = \frac{\mathcal{V}^s_t}{A^s_t}$
    - $\mathcal{V}^s_t$: # of shares traded; $A^s_t$: # of outstanding shares
  - aggregate: $T^l_t = \frac{1}{n} \sum_{s=1}^{n} T^s_t$

- **Proxies for the policy rate**
  - 3-month Eurodollar futures rate (CME Group)
  - tick-by-tick 30-day fed funds futures rate (CME Group)

- **Sample**
  - all common stocks in NYSE (1300-1800 stocks, from CRSP)
  - 1994-2001, 2014 trading days, 73 FOMC announcement dates
Event-study (Bernanke and Kuttner, 2005)

\[ Y_t = a + b \Delta i_t + \varepsilon_t \]

- \( \Delta i_t \equiv i_t - i_{t-1} \): proxy for unexpected change in policy rate
- \( i_t \): day-\( t \) nominal interest rate implied by 3-month Eurodollar futures with closest expiration after day \( t \)
- \( t \in S_1 \) (sample of 73 FOMC policy announcement days)

- Regression 1: \( Y_t = R_t^l \)
- Regression 2: \( Y_t = T_t^l - T_{t-1}^l \)
Heteroskedasticity-based (Rigobon and Sack, 2004)

\[ Y_t = \alpha \Delta i_t + X_t + \varepsilon_t \quad \text{and} \quad \Delta i_t = \beta Y_t + \gamma X_t + \eta_t \]

- Two potential concerns with event-study approach:
  - \( \Sigma \varepsilon > 0 \) and \( \beta \neq 0 \) \( \Rightarrow \) simultaneity bias
  - \( \Sigma X > 0 \) and \( \gamma \neq 0 \) \( \Rightarrow \) omitted variable bias

- Idea: consider two subsamples
  - \( S_1 \): subsample of FOMC-announcement days
  - \( S_0 \): subsample of non FOMC-announcement days

If \( \Sigma^0_\eta < \Sigma^1_\eta \) (variance of \( \eta_t \) is larger in \( S_1 \) than in \( S_0 \)), \( \alpha \) is identified from the difference between the covariance matrix of \( Y_t \) and \( \Delta i_t \) computed in \( S_1 \) and in \( S_0 \)

- Regression 1: \( Y_t = R_t^l \), Regression 2: \( Y_t = T_t^l - T_{t-1}^l \)
Event study with high-frequency instrumental variable

$$Y_t = a + b\Delta i_t + \varepsilon_t$$

- Event-study concerns:
  - Omitted variable bias
  - Eurodollar futures rate may respond to $Y_t$ on policy days

- Instrument for $\Delta i_t$ with (unexpected) change in a *narrow 30-minute window* around the FOMC announcement

- For each $t \in S_1$ define $z_t \equiv i_{t,m_t^*+20} - i_{t,m_t^*-10}$
  - $i_{t,m}$: daily 30-day Fed Funds futures rate on minute $m$ of day $t$
  - $m_t^*$: minute of day $t$ when FOMC announcement is made

- Estimate $b$ on sample $S_1$ using $z_t$ as HFIV for $\Delta i_t$
Impact of monetary policy on returns and turnover

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On the day of the announcement, a 25 bp increase in policy rate ⇒

- stock return declines by .94%, 1.56%, or 2.14%
- turnover rate decline in the range 17% to 30%
  (e.g., (.0025/4)/.0037≈.17)
Announcement-day effects across liquidity portfolios

1. For each policy date, $t$, calculate $T_t^s$ as the average turnover rate of an individual stock, $s$, over all trading days during the four weeks prior to the policy date.

2. Stocks with $T_t^s$ between $[5 (i - 1)]^{th}$ percentile and $(5i)^{th}$ percentile are sorted into the $i^{th}$ portfolio, $i = 1, ..., 20$.

3. Estimate announcement-day effects for each portfolio.
## Announcement-day effects across liquidity portfolios

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Liquidity portfolios: returns and turnover (E-based)
Liquidity portfolios: returns and turnover (H-based)
Liquidity portfolios: returns and turnover (HFIV)
Announcement-day effects for individual stocks (E-based)

\[ R^s_t = \beta_0 + \beta_1 \Delta i_t + \beta_2 T^s_t + \beta_3 \overline{T^s_t} \times \overline{\Delta i_t} + D_s + D_t + \beta_4 (\Delta i_t)^2 + \beta_5 (T^s_t)^2 + \varepsilon_{st} \]

- \( \Delta i_t \): announcement-day change in 3-month Eurodollar futures rate
- \( T^s_t \): average turnover rate of individual stock \( s \) over all trading days during the four weeks prior to policy date
- \( \overline{T^s_t} \equiv (T^s_t - \overline{T}) \) and \( \overline{\Delta i_t} \equiv (\Delta i_t - \Delta i) \)
- \( D_s \): stock fixed effect; \( D_t \): quarterly time dummy
- \( \varepsilon_{st} \): error term for stock \( s \) on policy announcement day \( t \)

Theory suggests \( \beta_3 < 0 \)
Announcement-day effects for individual stocks (E-based)

\[ \mathcal{R}_t^s = \beta_0 + \beta_1 \Delta i_t + \beta_2 \mathcal{T}_t^s + \beta_3 \overline{\mathcal{T}_t^s} \times \Delta i_t + D_s + D_t + \beta_4 (\Delta i_t)^2 + \beta_5 (\mathcal{T}_t^s)^2 + \varepsilon_{st} \]

- \( \Delta i_t \): announcement-day change in 3-month Eurodollar futures rate
- \( \mathcal{T}_t^s \): average turnover rate of individual stock \( s \) over all trading days during the four weeks prior to policy date
- \( \overline{\mathcal{T}_t^s} \equiv (\mathcal{T}_t^s - \bar{T}) \) and \( \overline{\Delta i_t} \equiv (\Delta i_t - \Delta i) \)
- \( D_s \): stock fixed effect; \( D_t \): quarterly time dummy
- \( \varepsilon_{st} \): error term for stock \( s \) on policy announcement day \( t \)
- Theory suggests \( \beta_3 < 0 \)
Announcement-day effects for individual stocks (E-based)

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Dynamic responses of aggregate returns and turnover

\[ Y_t = \sum_{j=1}^{10} B_j Y_{t-j} + u_t \]

- \( Y_t = (i_t, R_t^l, T_t^l)' \) for every day in the sample
- \( i_t \): 3-month Eurodollar rate on day \( t \)
- \( R_t^l \): average stock-market return on day \( t \)
- \( T_t^l \): average stock-market turnover rate on day \( t \)
- External high-frequency instrument to identify money shocks
Dynamic responses of aggregate returns and turnover

**Stock return**

**Daily turnover rate**

**Stock return**

**Daily turnover rate**
Liquidity portfolios: dynamic responses
Liquidity portfolios: dynamic responses
Theory: monetary policy shocks and multiple assets

- \( \mu_t \sim M \)-state Markov chain \([\sigma_{ij}] \mid A_{t+1}^m = \mu_t A_t^m\)

- \(N\) asset classes \(\mid\) segmented OTC markets \(\mid\) different \(\alpha^s\)

- Investors choose \(\{a^s_{t+1}, a^{ms}_{t+1}\}_{s=1}^N\)
Equilibrium conditions

\[ \phi_i^s = \bar{\beta} \delta \sum_{j \in M} \sigma_{ij} \left[ \bar{\varepsilon} + \phi_j^s + \alpha^s \theta \int_{\varepsilon_L}^{\varepsilon_j^{s*}} (\varepsilon_j^{s*} - \varepsilon) dG(\varepsilon) \right] \]

\[ Z_i = \frac{\bar{\beta}}{\mu_i} \sum_{j \in M} \sigma_{ij} \left[ Z_j + \alpha^s \theta \int_{\varepsilon_j^{s*}}^{\varepsilon_j^H} (\varepsilon - \varepsilon_j^{s*}) dG(\varepsilon) \frac{Z_j}{\varepsilon_j^{s*} + \phi_j^s} \right] \]

\[ Z_i^s = \frac{G(\varepsilon_i^{s*}) A^s}{1 - G(\varepsilon_i^{s*})} (\varepsilon_i^{s*} + \phi_i^s) \]

\[ Z_i = \sum_{s \in \mathbb{N}} Z_i^s \]
Calibration

\[ y_{t+1} = e^{x_{t+1}} y_t \]
\[ x_{t+1} \sim \mathcal{N} (\bar{\gamma} - 1, \Sigma^2) \]
\[ \bar{\gamma} = 1 + \frac{.04}{365} \]
\[ \Sigma = \frac{.12}{\sqrt{365}} \]

number of asset classes
\[ N = 20 \]

asset supply
\[ A_s = 1 \]

distribution of asset liquidity
\[ \{\alpha^s\}_{s=1}^{20} \] estimated

monetary policy shocks
\[ \{\mu_i\}_{i=1}^7, \begin{bmatrix} \sigma_{ij} \end{bmatrix} \] estimated

discount factor
\[ \beta = (0.97)^{1/365} \]

bargaining power
\[ \theta = 1 \]

idiosyncratic shocks
\[ \epsilon \sim U [0, 1] \]

asset destruction
\[ \delta = (0.7)^{1/365} \]
The quantitative exercises

- Compute equilibrium price functions
- Feed into the model the actual path of the policy rate (3-month Eurodollar futures)
- Simulate 1000 dividend samples of equal length as data sample and compute equilibrium path for each sample
- **Exercise 1**: run aggregate event-study regression on each sample
- **Exercise 2**: for each asset class, run event-study on each sample
- **Exercise 3**: estimate VAR impulse responses on each sample (same specification and identification procedure as empirical work)
- For each exercise, report distribution of estimates across simulations
## Announcement-day effects on returns and turnover

<table>
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<th></th>
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<th>HFIV</th>
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Announcement-day effects on returns (E-based)

Estimates of Response of Stock Return to Policy Rate

- Basis Points (per 1 bp increase in policy rate)
- Frequency

- Model Distribution
- Data Estimate
- 5-95 percentiles
Liquidity portfolios: returns and turnover (E-based)
Liquidity portfolios: returns and turnover (E-based)
Dynamic responses of aggregate returns and turnover
Summary

- What are the effects of monetary policy on the stock market?
Summary

- What are the effects of monetary policy on the stock market?
Summary

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Unanticipated tightening causes sizeable declines in returns and turnover. These effects are larger for more liquid stocks.
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Summary

- **What are the effects of monetary policy on the stock market?**

  Unanticipated tightening causes sizeable declines in returns and turnover. These effects are larger for more liquid stocks.

- **What is the mechanism?**

  We documented, modeled, and quantified a new mechanism: the turnover-liquidity transmission mechanism of monetary policy.
Summary

- *What are the effects of monetary policy on the stock market?*

  Unanticipated tightening causes sizeable declines in returns and turnover. These effects are larger for more liquid stocks.

- *What is the mechanism?*

  We documented, modeled, and quantified a new mechanism: the turnover-liquidity transmission mechanism of monetary policy.

  - tight money $\Rightarrow$ scarcer means of payment $\Rightarrow$ turnover falls $\Rightarrow$ price falls
To do ...

- Study other assets
- Endogenize $\alpha^s$
- Incorporate leverage (realistic, likely to improve model fit)
end.
Monetary policy, OTC frictions, and asset prices
VAR identification with high-frequency external instrument

\[ KY_t = \sum_{j=1}^{J} C_j Y_{t-j} + \varepsilon_t \quad \text{(SVAR)} \]
\[ Y_t = \sum_{j=1}^{J} (K^{-1} C_j) Y_{t-j} + u_t \quad \text{(VAR)} \]
\[ u_t = K^{-1} \varepsilon_t \quad \text{(RFR)} \]
\[ E(\varepsilon_t \varepsilon_t') = K^{-1} K^{-1}' \quad \text{(IC1)} \]

- \( K, C_j: n \times n \) matrices
- \( \varepsilon_t \in \mathbb{R}^n, E(\varepsilon_t) = 0, E(\varepsilon_t \varepsilon_t') = I, E(\varepsilon_t \varepsilon_s') = 0 \) for \( s \neq t \)
- The identification problem:
  - want to find \( n^2 \) elements of \( K^{-1} \)
  - condition (IC1) provides \( n(n + 1)/2 \) independent conditions
  - need \( n(n - 1)/2 \) additional conditions
VAR identification with high-frequency external instrument

\[ Y_t = \begin{pmatrix} i_t, \mathcal{R}_t, \mathcal{T}_t \end{pmatrix}', \quad \varepsilon_t = \begin{pmatrix} \varepsilon^i_t, \varepsilon^R_t, \varepsilon^T_t \end{pmatrix}', \quad u_t = \begin{pmatrix} u^i_t, u^R_t, u^T_t \end{pmatrix}' \]

\[ u_t = K^{-1} \varepsilon_t \quad \text{(RFR)} \]

\[ K^{-1} = \begin{bmatrix} k^i_i & k^R_i & k^T_i \\ k^R_i & k^R_R & k^T_T \\ k^T_i & k^T_T & k^T_T \end{bmatrix} \]

\[ \Rightarrow \]

\[ \begin{bmatrix} u^i_t \\ u^R_t \\ u^T_t \end{bmatrix} = \begin{bmatrix} k^i_i & k^R_i & k^T_i \\ k^R_i & k^R_R & k^T_T \\ k^T_i & k^T_T & k^T_T \end{bmatrix} \begin{bmatrix} \varepsilon^i_t \\ \varepsilon^R_t \\ \varepsilon^T_t \end{bmatrix} + \begin{bmatrix} k^T_i \\ k^T_R \\ k^T_T \end{bmatrix} \varepsilon^T_t + \begin{bmatrix} k^R_i \\ k^R_R \\ k^T_T \end{bmatrix} \varepsilon^R_t + \begin{bmatrix} k^T_i \\ k^T_R \\ k^T_T \end{bmatrix} \varepsilon^T_t \]
VAR identification with high-frequency external instrument

Find instrument $z_t$ for $\varepsilon^i_t$, i.e.,

$$\mathbb{E}(z_t \varepsilon^R_t) = \mathbb{E}(z_t \varepsilon^T_t) = 0 < \mathbb{E}(z_t \varepsilon^i_t) \equiv v \text{ for all } t$$

$$\Rightarrow$$

$$\Lambda \equiv \mathbb{E}(z_t u_t) = K^{-1} \mathbb{E}(z_t \varepsilon_t) = (k^i_t, k^R_t, k^T_t)' v$$

Since $\Lambda = (\Lambda_1, \Lambda_2, \Lambda_3)'$ is a known $(3 \times 1)$ vector,

$$\begin{align*}
\Lambda_1 & = \frac{vk^i_t}{vk^R_t} = \Lambda_2 \\
\Lambda_2 & = \frac{k^R_t}{k^i_t} = \frac{\Lambda_2}{\Lambda_1} \quad \text{and} \quad \frac{k^T_t}{k^i_t} = \frac{\Lambda_3}{\Lambda_1}
\end{align*}$$

- $\frac{\Lambda_2}{\Lambda_1} = \frac{\mathbb{E}(z_t u^R_t)}{\mathbb{E}(z_t u^i_t)}$ : slope of regression of $u^R_t$ on $u^i_t$ proxied with $z_t$
- $\frac{\Lambda_3}{\Lambda_1} = \frac{\mathbb{E}(z_t u^T_t)}{\mathbb{E}(z_t u^i_t)}$ : slope of regression of $u^T_t$ on $u^i_t$ proxied with $z_t$
- Our instrument: $z_t = i_{t,m_t^*+20} - i_{t,m_t^*-10}$ (on subsample $S_1$)
VAR: choice of number of lags

- Akaike information criterion: 10 lags
- Schwarz’s Bayesian information criterion: 5 lags
- Hannan and Quinn information criterion: 5 lags
- Check how well these specifications estimate the true theoretical impulse responses (simulations of length equal to data sample)
VAR: choice of number of lags

- Compute equilibrium functions for calibrated model
- Set policy rate to follow the AR(1) process estimated from data
- Compute true theoretical IR to a 1bp increase in the policy rate
- Simulate 1000 samples of the dividend and the policy rate

- For each sample:
  - compute equilibrium paths for \( \{ R_t^l \} \) and \( \{ T_t^l \} \)
  - estimate baseline VAR with 5 and 10 lags. Compute IR to 1bp increase in policy rate (with HFIV identification scheme)

- For version with 5 and 10 lags, report median IR and 95% confidence intervals (from distribution of estimates). Compare with true theoretical IR
VAR: choice of number of lags
VAR: confidence intervals for impulse responses

- **Recursive wild bootstrap** to compute 95% confidence intervals for estimated IR coefficients (Gonçalves and Kilian, 2004)

- Given VAR estimates, \( \{ \hat{B}_j \}_{j=1}^J \) and \( \{ \hat{u}_t \} \), generate bootstrap draws, \( \{ Y^b_t \} \), by

  \[
  Y^b_t = \sum_{j=1}^J \hat{B}_j Y_{t-j} + e^b_t \hat{u}_t
  \]

  - \( e^b_t \) : the realization of a scalar random variable taking values of \(-1\) or \(1\), each with probability \(1/2\)

- HFIV identification procedure requires bootstrap draws for proxy variable, \( \{ z^b_t \} \). Generate random draws for the proxy variable via

  \[
  z^b_t = e^b_t z_t
  \]

  (Mertens and Ravn, 2013)

- Use the bootstrap samples \( \{ Y^b_t \} \) and \( \{ z^b_t \} \) to reestimate the VAR coefficients and compute the associated impulse responses. The confidence intervals are the percentile intervals of the distribution of 10,000 bootstrap estimates for the impulse response coefficients.
Impulse responses to a 1pp increase in the policy rate
Impulse responses to 1pp increase in policy rate (data)
Results for portfolios sorted on liquidity betas

\[ R_s^t = \alpha_s + \beta_{0}^s T_t^I + \beta_{1}^s \text{MKT}_t + \beta_{2}^s \text{HML}_t + \beta_{3}^s \text{SMB}_t + \epsilon_s^t \]

- For each stock \( s \), run it 73 times, once for each policy day \( t_k \), using sample of all trading days between day \( t_{k-1} \) and day \( t_k \)
- 292 betas estimated for each stock \( s \), i.e., \( \{ \{ \beta_j^s (k) \}_{j=0}^{3} \}_{k=1}^{73} \)
  where \( \beta_j^s (k) \) is for sample \( (t_{k-1}, t_k) \)
- For each policy day \( t_k \), stocks with \( \beta_0^s (k) \) between \( [5 (i-1)]^{th} \) percentile and \( (5i)^{th} \) percentile are sorted into the \( i^{th} \) portfolio, \( i = 1, \ldots, 20 \)
- Compute daily \( R_i^t \) and \( T_t^i - T_{t-1}^i \) for each portfolio
- Run event-study regressions portfolio-by-portfolio
## Results for portfolios sorted on liquidity betas

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<td>.0023</td>
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Liquidity-beta portfolios: exposure to Fama-French risk factors

\[ R_t^s = \alpha^s + \beta^s_0 T_t^l + \beta^s_1 MKT_t + \beta^s_2 HML_t + \beta^s_3 SMB_t + \varepsilon_t \]

- Construct the series of *monthly* return for each of the 20 portfolios for 1994-2001, \( \{(R_t^i)^{20}_{i=1}\} \)
- Run above regression to estimate \( \{\{\beta^i_j\}_{i=1}^{20}\}_{j=0}^3 \)
- For each factor \( j \), plot \( (i, \beta^i_j)^{20}_{i=1} \) 
  (normalize \( \{\beta^i_0\}_{i=1}^{20} \) by dividing it by \( |\beta^1_0| \))
Liquidity-beta portfolios: exposure to Fama-French risk factors
Response of returns: simple CAPM vs. liquidity-beta portfolios

Response of stock return to policy rate

- Actual response
- Response according to CAPM

Portfolio basis points (per 1 bp increase in policy rate)

0 2 4 6 8 10 12 14 16 18 20

Basis points (per 1 bp increase in policy rate)

0 5 10 15 20
### 3-month Eurodollar futures rate

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**Time Series of Policy Rate**

![Graph](image.png)
Rates: 3-month Eurodollar, effective Fed Funds, target

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Rates: 3-month Eurodollar futures, Fed Funds target rate
Rates: 3-month Eurodollar futures, effective Fed Funds
Rates: effective Fed Funds, Fed Funds target rate
Estimated monetary policy process

- $i_t$: 3-month Eurodollar futures rate on day $t$ (in bps)

- Estimate (1994-2001): $\ln i_t = (1 - \zeta) \ln i_0 + \zeta \ln i_{t-1} + \epsilon_t$

  $E(i_t) = 346$ bps  $SD(i_t) = 172$ bps  $\zeta = .9997652$

- Approximate AR(1) with 7-state Markov chain, $\{r_i, \sigma_{ij}\}_{i,j=1}^7$ (Rouwenhorst method, Galindev and Lkhagvasuren, 2010)

- Mapping between $\{r_i, \sigma_{ij}\}_{i,j=1}^7$ and $\{\mu_i, \sigma_{ij}\}_{i,j=1}^7$ given by

  $$r_i \approx \frac{\mu_i - \bar{\beta}}{\bar{\beta}}$$
# Announcement effects for liquidity portfolios: 1994-2007

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