The allocation of interest rate risk and the financial sector

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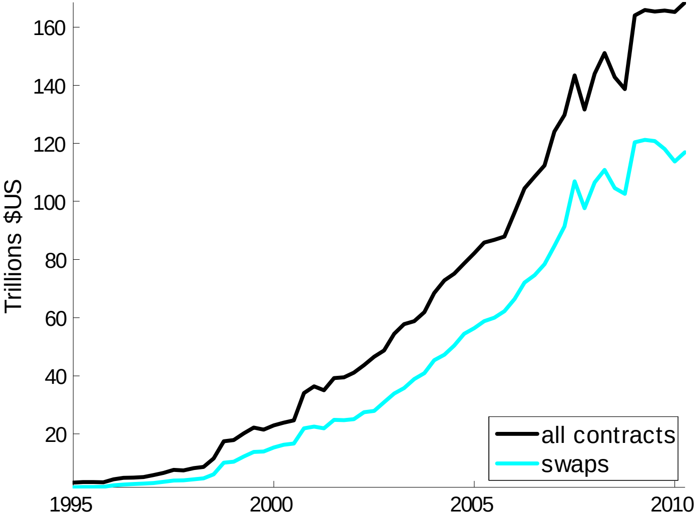
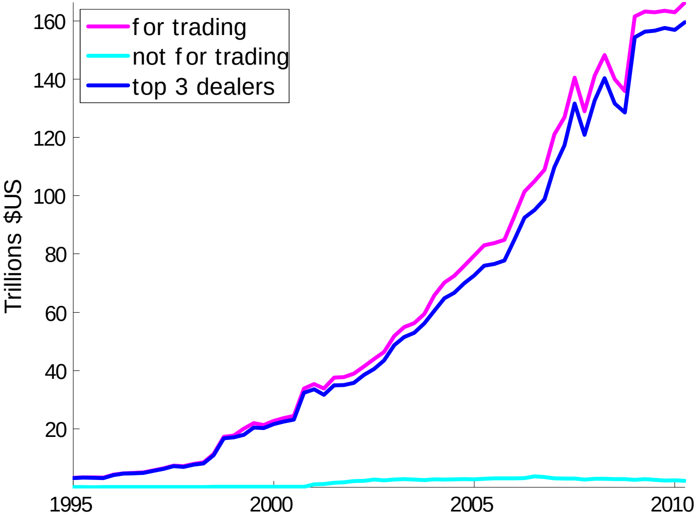
Motivation

- Financial institutions are exposed to interest rate risk
  - maturity transformation (loans & securities vs deposits)
  - derivatives
- How to describe bank positions & compare them?
  - to match to economic models
  - to assess how & why riskiness of banks varies over time
    - ★ do derivatives hedge other on-balance-sheet exposures?
    - ★ do bank strategies differ in the cross section?

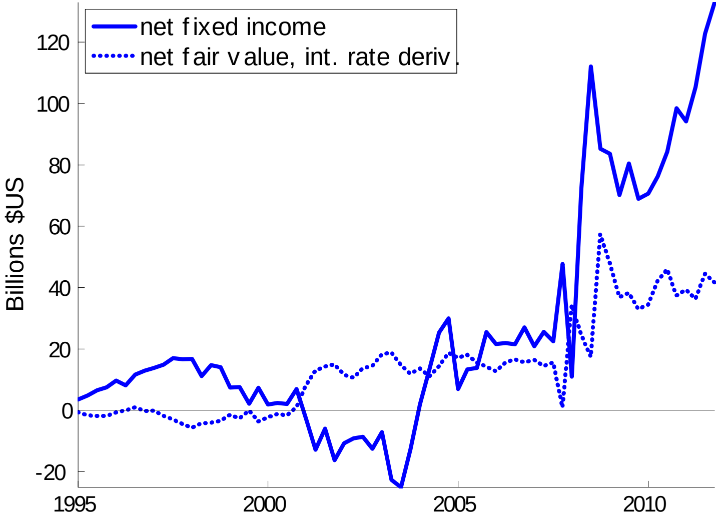
Notional Values of Interest Rate Derivatives



Concentrated Holdings of Interest Rate Derivatives



Fair Values: JP Morgan Chase



Overview

- data: bank positions in many fixed income instruments
  - organized by contract form (loan, deposit, swap etc.)

$\Longrightarrow$ size and direction of interest rate exposures?

- strategy: approximate positions as portfolios in a few bonds
  - works because values of instruments have a factor structure
  - makes instruments comparable & provides risk measures
- estimate portfolios from observables on each bank (separately for loans/deposits, securities, derivatives)
- compare across positions & banks

Related literature

- Interest exposure & derivative use
  - Flannery-James 84, Venkatachalam 96, Hirtle 97,...
- Derivatives positions
  - interest rate: Gorton-Rosen 95
  - credit: Stulz et al. 08, Hirtle 08
- Nonfinancial firms
  - who uses derivatives: Hentschel-Kothari 01, Jermann & Yue 12
  - market value of hedging: Allyanis-Weston 01, Jorion-Jin 06
  - economic magnitudes: Guay-Kothari 03
- Bank balance sheets
  - Adrian & Shin 08, Shin 11, He & Krishnamurthy 11
- Risk measurement for institutions
  - measures of tail risk (e.g., VaR literature) Acharya-Pederson-Philippon-Richardson 10, Kelly-Lustig-van Nieuwerburgh 11
  - "stress tests": Brunnermeier-Gorton-Krishnamurthy 12, Duffie 12,...

Outline

- Replication
  - basic argument
  - one factor implementation
  - loan & security replication
- Interest rate swaps
  - terminology & data
  - estimation of replicating portfolio
- Example results for large US banks

Replication with spanning securities

- Factor structure with normal shocks
  - consider payoff stream with value $\pi(f_t, t)$
  - factors $f_t = \phi f_{t-1} + \sigma\varepsilon_t, \quad \varepsilon_t \backsim \mathcal{N}(0, I_{K\times K})$
- Change in value of payoff stream π between t and $t+1$

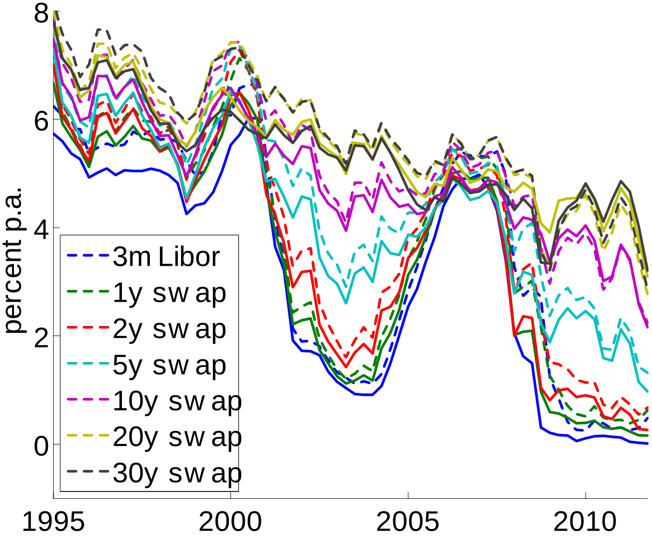
$$\pi(f_{t+1}, t+1) - \pi(f_t, t) \approx a_t^\pi + b_t^\pi \varepsilon_{t+1}$$

- form replicating portfolio from $K+1$ spanning securities
  - always include θ_t^1 1 period bonds ($=$ cash) with price e^{-i_t}
  - use $\hat{\theta}_t$ other securities, e.g. longer bonds
- choose $\theta_t^1, \hat{\theta}_t$ to match change in value π for all ε_{t+1}:

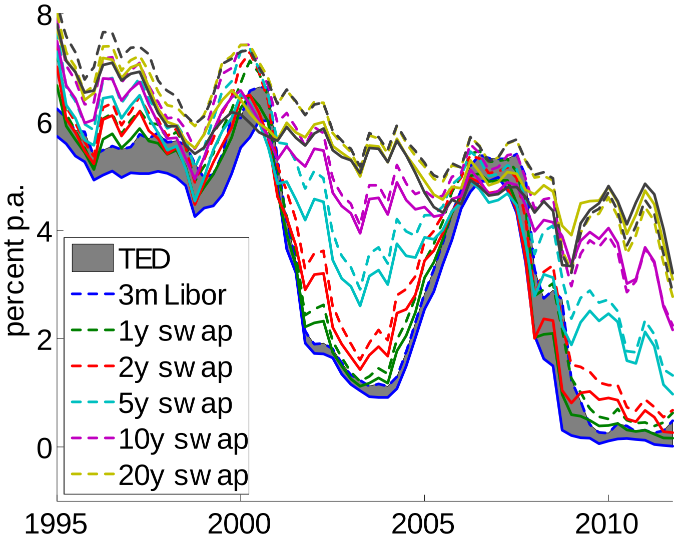
$$\begin{pmatrix} \theta_t^1 & \hat{\theta}_t' \end{pmatrix} \begin{pmatrix} e^{-i_t} i_t & 0 \\ \hat{a}_t & \hat{b}_t \end{pmatrix} \begin{pmatrix} 1 \\ \varepsilon_{t+1} \end{pmatrix} = \begin{pmatrix} a_t^\pi & b_t^\pi \end{pmatrix} \begin{pmatrix} 1 \\ \varepsilon_{t+1} \end{pmatrix}.$$

- no arbitrage: value of replicating portfolio at t $=$ value $\pi(f_t, t)$

Riskless (solid) & risky (dotted) zero coupon bond yields



Riskless (solid) & risky (dotted) zero coupon bond yields



Implementation with one factor

- single factor f_t = 2 year risky zero coupon yield from swap curve
- to relate value of other payoff streams π to f, estimate one factor model of risky & riskless bonds jointly
- pricing kernel

$$\begin{aligned} M_{t+1} &= \exp\left(-i_t - \frac{1}{2}\lambda_t^2 - \lambda_t \varepsilon_{t+1}\right) \\ \lambda_t &= l_0 + l_1 f_t \end{aligned}$$

- riskless zero coupon bonds

$$\begin{aligned} P_t^{(n)} &= E_t\left[M_{t+1} P_{t+1}^{(n-1)}\right], \qquad P_t^{(0)} = 1 \\ P_t^{(n)} &= \exp\left(A_n + B_n f_t\right) \end{aligned}$$

- find $B_n < 0$ (hi interest rates, low prices)
- also $\lambda_t < 0$ so E_t[excess return on n period bond] $= B_{n-1}\sigma\lambda_t > 0$

Credit risk

- risky bonds default; recovery value proportional to price
- knockoff per dollar invested

$$\Delta_{t+1} = \exp\left(-d_0 - d_1 f_t - \frac{1}{2} d_2^2 - d_2 \varepsilon_{t+1}\right)$$

- risky zero coupon prices

$$\begin{aligned} \tilde{P}_t^{(n)} &= E_t\left[M_{t+1}\Delta_{t+1}\tilde{P}_t^{(n-1)}\right], \qquad \tilde{P}_t^{(0)} = 1 \\ \tilde{P}_t^{(n)} &= \exp\left(\tilde{A}_n + \tilde{B}_n f_t\right) \end{aligned}$$

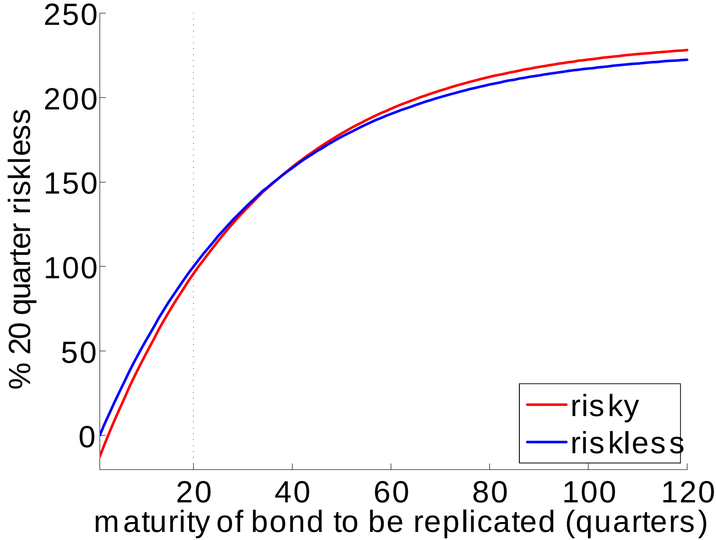
- parameters d describe spreads, e.g. risky short rate

$$\tilde{\imath}_t = i_t + d_0 + d_1 f_t - d_2' \lambda_t$$

- estimation finds
  - $d_1 > 0$ (spreads high when rates high)
  - $d_2 < 0$ ($d_2 \lambda_t > 0$ compensates for risk of drop in rates)

Replication with cash & 20 qtr riskless

with one factor model $a_t^\pi + b_t^\pi \varepsilon_{t+1} = \pi_t \left(i_t + \hat{\alpha}^\pi \left(\lambda_t + \varepsilon_{t+1} \right) \right)$



Replication of bank positions

- Loans
  - derive stream of promised payments from book value & interest rate data
  - view stream of promises as bundle of risky zero coupon bonds
  - replicate as above
- Securities
  - observe fair values by maturity & issuer (private, government)
  - use risky, riskless prices to compute book values
  - replicate as above
  - bonds held for trading: rough assumptions on maturity
- Deposits & money market funds
  - mostly short term (= cash)
- Next: replication of interest rate derivatives

Interest rate swaps

- Terminology
  - swap = agreement to exchange streams of interest rate payments
  - payments $\propto$ notional amount N, up to maturity m
  - fixed leg = stream of payments at *swap rate s* + notional at maturity
  - floating leg = market short rate
  - "pay-fixed" swap: pay fixed payments, receive floating payments
  - conversely, "pay-floating" swap
- Value of fixed leg: discount with bond prices $\tilde{P}_t^{(n)}$

$$\text{PV(fixed leg)} = N \cdot \left(\sum_{i=1}^{m} s \cdot \tilde{P}_t^{(i)} + \tilde{P}_t^{(m)} \right)$$

- Value of floating leg:

$$\text{PV(floating leg)} = N$$

- Fair value of pay fixed swap = PV(floating leg) – PV (fixed leg)

Fair values of interest rate swaps

- Fair value of pay fixed (receive floating) swap with notional 1:

$$F_t(m,s) = 1 - \left[\sum_{i=1}^{m} s \cdot \tilde{P}_t^{(i)} + 1 \cdot \tilde{P}_t^{(m)}\right]$$

- At inception date, swap rate set s.t. $F_t(m,s) = 0$
- Once s locked in & fair value moves with bond prices:
  - fair value falls if bond prices rise (interest rates fall, lower floating payments received)
  - fair value rises if bond prices fall (interest rates rise, higher floating payments received)
- Available data
  - bank notionals N_t & fair value FV_t
  - market swap rates s_t
  - do not observe direction (pay fixed or floating)
- Use state space model to infer swap position from fair values & history of interest rates

Gross versus net positions

- Dealers incorporate bid ask spread ξ into swap rates
- $s =$ "midmarket" swap rate; quotes are $s \pm \xi/2$
- Dealer's fair value on N^{fix} notionals pay fixed

$$F_t\left(m, s - \xi/2\right)\ N^{fix} = \left(1 - \sum_{i=1}^{m}(s - \xi/2) \cdot \tilde{P}_t^{(i)} - \tilde{P}_t^{(m)}\right) N^{fix}$$

- Dealer's fair value on N^{fl} notional pay floating

$$-F_t\left(m, s + \xi/2\right)\ N^{fl} = \left(\sum_{i=1}^{m}(s + \xi/2) \cdot \tilde{P}_t^{(i)} + \tilde{P}_t^{(m)} - 1\right) N^{fl}$$

- Add up for net net pay-fixed position

$$\left(N^{fix} - N^{fl}\right) F_t\left(s, m\right) + \left(N^{fix} + N^{fl}\right)\ \xi\ \sum_{i=1}^{m} \tilde{P}_t^{(i)}$$

- Get 2nd term from data on total notionals & bidask spreads
- Now estimate first term

State space model of net swap positions

- Replicate net position with portfolio of cash and "spanning swap"
- State variables:

$$\begin{aligned} \omega_t &= \text{net spanning swap position (pay-fixed!) / notionals} \\ K_t &= \text{cash position / notionals} \\ \bar{s}_t &= \text{locked swap rate} \end{aligned}$$

- Given last period's strategy

$$\text{net fair value}(t) = \left[\omega_{t-1} F_t \left(m-1, \bar{s}_{t-1}, (\tilde{P}_t^{(n)})\right) + K_{t-1}\right] N_{t-1}$$

- State space representation of ratio net fair value/notionals

$$\begin{aligned} \frac{\text{net fair value(t)}}{\text{notionals(t-1)}} &= \omega_{t-1} F_t \left(m-1, \bar{s}_{t-1}, (\tilde{P}_t^{(n)})\right) + K_{t-1} + u_t \\ (\omega_t, K_t, \bar{s}_t) &= T_t \left(\omega_{t-1}, K_{t-1}, \bar{s}_{t-1}\right) \end{aligned}$$

- Transition captures
  - updating of maturities: from ω_{t-1} (end of t-1) to $\tilde{\omega}_t$ (beginning of t)
  - swap trading: from $\tilde{\omega}_t$ (beginning of t) to ω_t (end of t)

Swap trading

- Transition equation for state variables

$$(\omega_t, \bar{s}_t, K_t) = T_t\left(\omega_{t-1}, \bar{s}_{t-1}, K_{t-1}\right)$$

- From $(\tilde{\omega}_t, \tilde{K}_t)$ (beginning of period) to (ω_t, K_t) (end of period)
- Two possible swap trades
  1. increasing exposure: start new swaps ω_t^{new} notionals(t)
     adjust swap rate proportionately to share of new swaps
  2. decreasing exposure: offset a fraction γ_t of the existing old swaps
     swap rate does not change
- Swap position after trading at t

$$\omega_t \text{ notionals(t)} = (1-\gamma_t)\,\tilde{\omega}_t \text{ notionals(t-1)} + \omega_t^{new} \text{ notionals(t)}$$

- Assume only one type of trade occurs every period...
  .. except when switching direction ($\gamma_t = 1$ and $\omega_t = \omega_t^{new}$)

State space representation: estimation

- State space representation for bank's ratio fair value / notional value

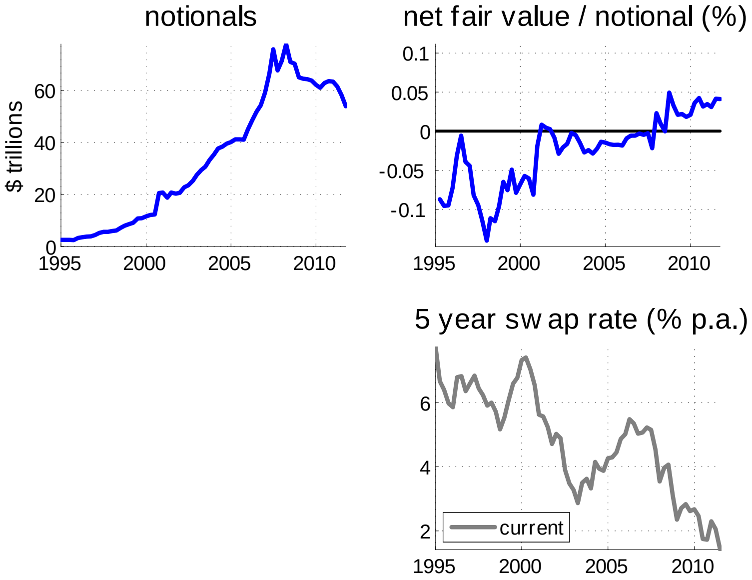
$$
\begin{aligned}
\frac{\text{net fair value(t)}}{\text{notionals(t-1)}} &= \omega_{t-1} F_t\left(m-1, \bar{s}_{t-1}\right) + K_{t-1} + u_t \\
\left(\omega_t, \bar{s}_t, K_t\right) &= T_t\left(\omega_{t-1}, \bar{s}_{t-1}, K_{t-1}\right)
\end{aligned}
$$

- Transition equation implies

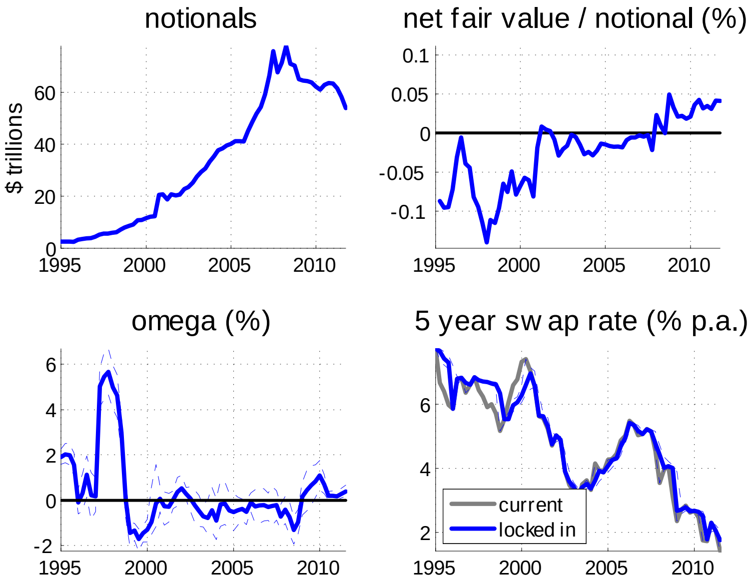
$$
\text{sequence } \left\{\omega_t\right\}_{t=1}^{T}, \bar{s}_1, K_1 \Rightarrow \text{ unique sequences } \left\{\bar{s}_t, K_t\right\}_{t=2}^{T}
$$

- Bayesian estimate of $\left\{\omega_t\right\}$ derived by MCMC
  - $\omega =$ random walk with iid normal innovations
  - uninformative gamma priors for variances of innovations, measurement error
  - initial conditions for 1995 $K_1 = 0$, $\bar{s}_1 =$ current swap rate

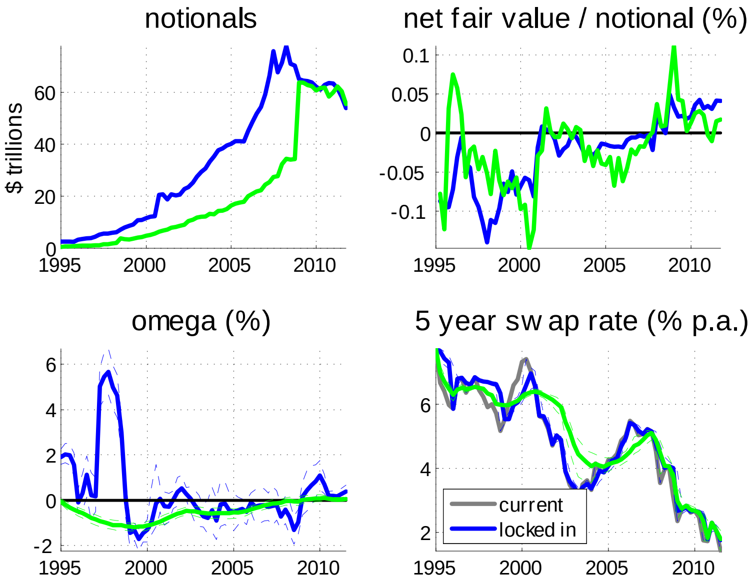
JP Morgan Chase: swap position



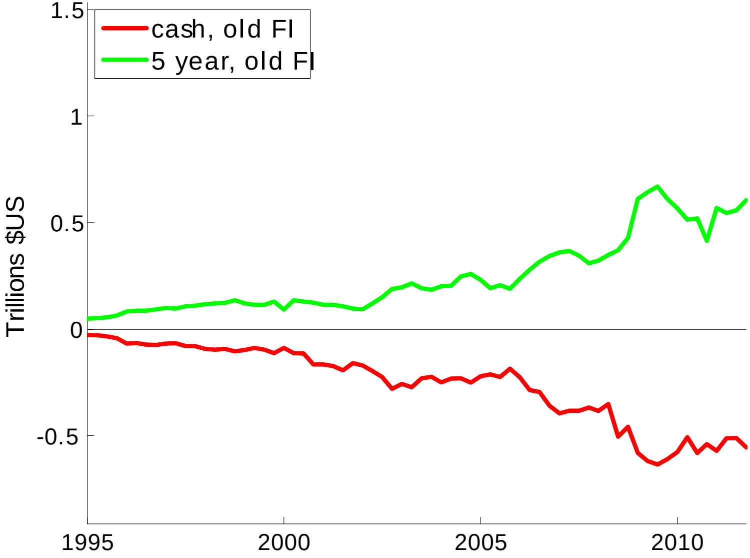
JP Morgan Chase: swap position



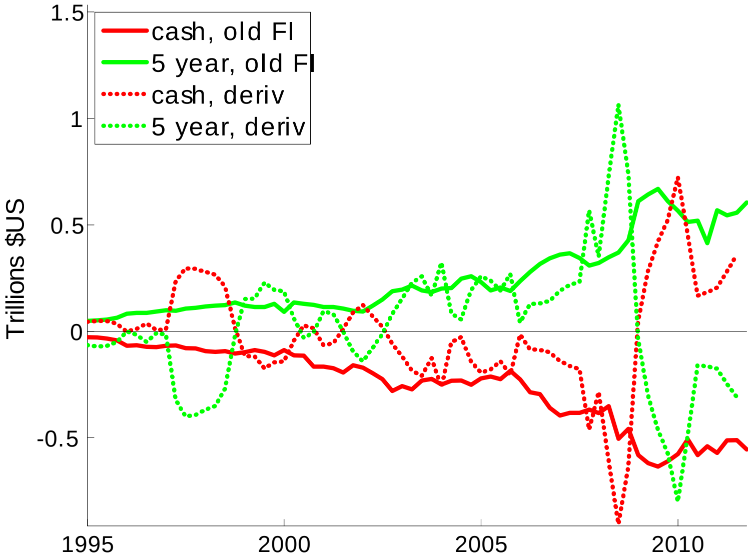
JPMorgan Chase (blue) & BofA (green): swap positions



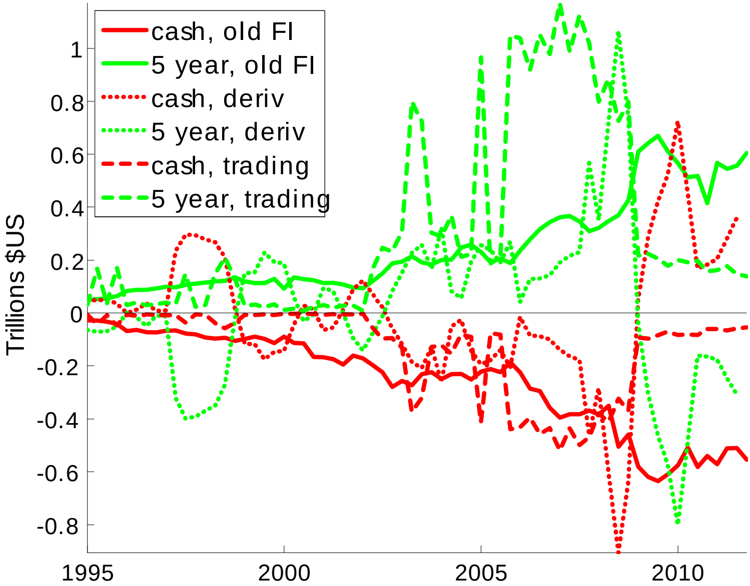
JP Morgan Chase: replicating portfolios

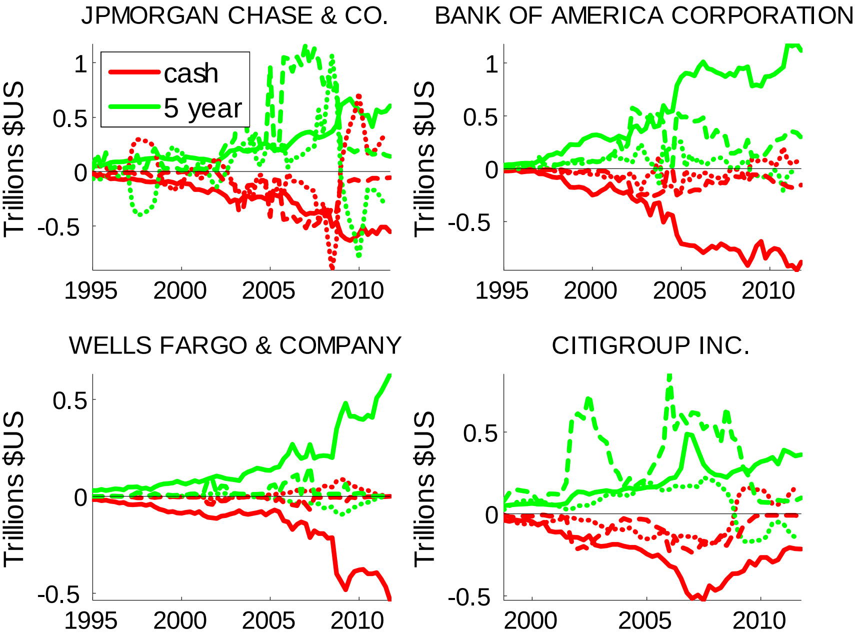


JP Morgan Chase: replicating portfolios



JP Morgan Chase: replicating portfolios




JPMORGAN CHASE & CO.
BANK OF AMERICA CORPORATION
WELLS FARGO & COMPANY
CITIGROUP INC.
Trillions $US
cash
5 year
1
0.5
0
-0.5
1995
2000
2005
2010

Summary

- Methodology to measure exposures in bank positions:
  Accounting data (e.g. in Bank call reports, SEC filings)
  Loans, deposits, securities etc.:
  maturity information, face/fair values
  Derivatives (mostly swaps):
  Bayesian estimation of net exposure under assumptions on trading
- Results for top dealer banks
  Derivatives further increase exposure to interest rate risk
  when rates fell, gains from floating positions
- Currently working on
  - investment banks (annual report data before 2009)
  - idiosyncratic default & role of CDS
  - refine valuation (trading assets, prepayment options)
- Future work
  - other factors (slope, credit, liquidity)