Banks’ Risk Exposures

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## Modern Bank Balance Sheet, JP Morgan Chase 2011

Total assets/liabilities: $2.3 Trillion

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash</td>
<td>Equity</td>
</tr>
<tr>
<td>Securities</td>
<td>Deposits</td>
</tr>
<tr>
<td>Loans</td>
<td>Other borrowed money</td>
</tr>
<tr>
<td>Fed funds + Repos</td>
<td>Fed funds + Repos</td>
</tr>
<tr>
<td>Trading assets</td>
<td>Trading liabilities</td>
</tr>
<tr>
<td>Other assets</td>
<td>Other liabilities</td>
</tr>
</tbody>
</table>

| 6%                  | 8%                   |
| 16%                 | 50%                  |
| 31%                 | 15%                  |
| 17%                 | 10%                  |
| 20%                 | 6%                   |
| 10%                 | 11%                  |

Derivatives: $60 Trillion Notionals of Swaps
Portfolio approach to measuring risk exposure

- Many positions: how to compress & compare?
- Basic idea: represent as simple portfolios
  - statistical evidence: cross section of bonds driven by “few shocks”
    - can replicate *any* fixed income position by portfolio of “few bonds”
- Portfolios = additive measure of risk & exposure, comparable
  - across positions (do derivative holdings hedge other business?)
  - across institutions (systemic risk?)
  - to simple portfolios implied by economic models
Ingredients

- Valuation model
  - parsimonious representation of cross section of bonds
  - allow for interest rate and credit risk
  - can depend on calendar time; cross sectional fit is key
  - this paper: one shock = shift in level of BB bond yield

- Bank data requirements
  - maturity & credit risk by position \(\rightarrow\) payment streams
  - detailed data on loans & securities \(\rightarrow\) apply valuation model directly
  - coarser data (e.g. derivatives) \(\rightarrow\) estimate positions first

- Results for large US banks
  - traditional business = long bonds financed by short debt
  - interest rate derivatives often do not hedge traditional business
  - similar exposures to aggregate risk across banks
Related literature

- Bank regulation (Basel II):
  - separately consider credit & market risk
  - credit risk: default probabilities from credit ratings or internal statistical models
  - capital requirements for different positions
  - look at positions one by one

- Measures of exposure
  - regress stock returns on risk factor, e.g. interest rates
    Flannery-James 84, Venkatachalam 96, Hirtle 97, English, van den Heuvel, Zakrajsek 12, Landier, Sraer & Thesmar 13...
  - stress tests: Brunnermeier-Gorton-Krishnamurthy 12, Duffie 12

- Measures of tail risk (VaR etc.)
  - Acharya-Pederson-Philippon-Richardson 10, Kelly-Lustig-van Nieuwerburgh 11

- Bank position data
  - derivatives: Gorton-Rosen 95, Stulz et al. 08, Hirtle 08
  - crisis: Adrian & Shin 08, Shin 11, He & Krishnamurthy 11
Outline

- Replication with spanning securities
  - bond/debt positions \(\approx\) simple portfolios in a few bonds
- One factor model of bond values
  - fit to bonds with & without credit risk
- Replication of loans, securities & deposits
- Interest rate swaps
  - definitions and 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 $f_t = \mu (f_t, t) + \sigma_t \epsilon_t, \; \epsilon_t \sim \mathcal{N} (0, I_K \times K)$

- Change in value of payoff stream $\pi$ between $t$ and $t + 1$
  $$\pi (f_{t+1}, t + 1) - \pi (f_t, t) \approx a_t^\pi + b_t^\pi \epsilon_{t+1}$$

- form replicating portfolio from $K + 1$ spanning securities
  - always include $\theta^1_t$ one period bonds ( = cash) with price $e^{-i_t}$
  - use $\hat{\theta}_t$ other securities, e.g. longer bonds

- choose $\theta^1_t, \hat{\theta}_t$ to match change in value $\pi$ for all $\epsilon_{t+1}$:
  $$\begin{pmatrix} \theta^1_t & \hat{\theta}'_t \end{pmatrix} \begin{pmatrix} e^{-i_t} i_t & 0 \\ \hat{a}_t & \hat{b}_t \end{pmatrix} \begin{pmatrix} 1 \\ \epsilon_{t+1} \end{pmatrix} = \begin{pmatrix} a_t^\pi & b_t^\pi \end{pmatrix} \begin{pmatrix} 1 \\ \epsilon_{t+1} \end{pmatrix}.$$

- no arbitrage: value of replicating portfolio at $t = \text{value } \pi (f_t, t)$
Implementation with one factor

- **single factor** $f_t =$ credit risky short rate (BB rating)
- to relate value of other payoff streams $\pi$ to $f$, estimate joint distribution of risky & riskless yields
- pricing kernel

\[
M_{t+1} = \exp(-\delta_0 - \delta_1 f_t - \lambda_t \varepsilon_{t+1} + \text{Jensen term})
\]
\[
\lambda_t = l_0 + l_1 f_t
\]

- riskless zero coupon bond prices as functions of $f_t$

\[
P_t^{(n)} = E_t \left[ M_{t+1} P_{t+1}^{(n-1)} \right], \quad P_t^{(0)} = 1
\]
\[
P_t^{(n)} = \exp(A_n + B_n f_t)
\]

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

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

\[ \Delta_{t+1} = \exp \left( -d_0 - d_1 f_t - (\tilde{\lambda}_t - \lambda_t) \varepsilon_{t+1} + \text{Jensen term} \right) \]

\[ \tilde{\lambda}_t = \tilde{l}_0 + \tilde{l}_1 f_t \]

- risky zero coupon prices

\[ \tilde{P}_t^{(n)} = E_t \left[ M_{t+1} \Delta_{t+1} \tilde{P}_t^{(n-1)} \right], \quad \tilde{P}_t^{(0)} = 1 \]

\[ \tilde{P}_t^{(n)} = \exp (\tilde{A}_n + \tilde{B}_n f_t) \]

- spreads

\[ \tilde{i}_t - i_t = d_0 + d_1 f_t \]

- estimation finds

  - \( d_1 > 0 \) spreads high when credit risk is high
  - \( \tilde{B}_n < 0 \) (high interest rates or default risk, low prices)
  - \( \tilde{\lambda}_t > \lambda_t \) low payoff when credit risk \( \varepsilon_{t+1} \) high
  - \( E_t[\text{excess return}] = (\tilde{B}_{n-1} \sigma - (\tilde{\lambda}_t - \lambda_t)) \lambda_t > 0 \)
Replication with one factor

- Change in bond value $\pi_t = \pi(f_t, t)$

  $$\pi_{t+1} - \pi_t \approx \pi_t \left( \mu_t + \sigma_t \varepsilon_{t+1} \right)$$

  expected return volatility

- Cash

  $$\mu_t = i_t, \quad \sigma_t = 0$$

- Represent other bond $\tilde{\pi}_t = \tilde{\pi}(f_t, t)$ as simple portfolio

  $$\tilde{\pi}_t (\tilde{\mu}_t + \tilde{\sigma}_t \varepsilon_{t+1}) = \omega_t \pi_t (\mu_t + \sigma_t \varepsilon_{t+1}) + K_t i_t$$

- $\pi = \text{value of 5-year riskless bond}$
- Simple portfolios = holdings $\omega_t$ of 5-year riskless bond & cash $K_t$
- Portfolio weight on 5-year bond increasing in maturity, risk of $\tilde{\pi}$
  - 2 year Treasury: 40% 5-year bond, 60% cash
  - 10 year Treasury: 140% 5-year bond, −40% cash
  - 10 year BBB corporate bond: 180% 5-year bond, −80% cash
Outline

• Basic replication argument
  ▶ bond/debt positions \( \approx \) simple portfolios in a few bonds

• One factor model of bond values
  ▶ fit to bonds with & without credit risk

• Replication of loans, securities, deposits

• Interest rate swaps
  ▶ definitions and data
  ▶ estimation of replicating portfolio

• Example results for large US banks
From regulatory data to simple portfolios

- Quarterly Call report data on bank balance sheets
  - loans: book value, maturity, credit quality
  - securities: fair values, maturity, credit quality
  - cash, deposits & fed funds

- Loans
  - start from data on book value & interest rates
  - derive stream of promises = bundle of (risky) zero coupon bonds
  - replicate with simple portfolio as above

- Securities
  - observe fair values by maturity & issuer (private, government)
  - use public, private bond prices to compute simple portfolio
  - bonds held for trading: rough assumptions on maturity

- Deposits & money market funds
  - mostly short term (= cash)

- Represent as simple portfolios in 5-year bond & cash
JP Morgan Chase: simple portfolio holdings

![Graph showing trillions of US cash and old FI holdings from 1996 to 2011. The graph includes two lines: red for cash, old FI and green for 5 year, old FI. There is a significant increase in the green line around 2008, followed by a steep decline.](image-url)
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Notionals of Interest Rate Derivatives of US Banks

- **1995\text{–}2000\text{–}2005\text{–}2010**
- **20\text{–}40\text{–}60\text{–}80\text{–}100\text{–}120\text{–}140\text{–}160**
- **Trillions $US**
- **all contracts\swaps**

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Swap payoffs

- Counterparties swap fixed vs floating payments $\propto$ notional value $N$

Payments, Example: 1-Year Swap, Notional = $1

- Direction of position: pay-fixed swap or pay-floating swap
- "fixed leg" := fixed payments + $N$ at maturity; value falls w/ rates
- "floating leg": = floating payments + $N$ at maturity; value = $N$
Valuation of swaps

- Discount fixed leg payoffs w/ bond price $P_{t}^{(m)}$, annuity price $C_{t}^{(m)}$

  \[
  \text{value of fixed leg} = N \left( s \, C_{t}^{(m)} + P_{t}^{(m)} \right)
  \]

- Direction: $d = 1$ for pay fixed, $-1$ for pay floating

- Fair value of individual swap position $(d, m, s)$
  \[
  N \, d \left( 1 - \left( s \, C_{t}^{(m)} + P_{t}^{(m)} \right) \right) =: N \, d \, F_{t} (s, m)
  \]

- Inception date: swap rate set s.t. $F_{t} (s, m) = 0$

- After inception date
  - pay fixed swap gains $\Leftrightarrow$ rates increase
  - pay floating swap gains $\Leftrightarrow$ rates fall

- Fair value of bank’s swap book
  \[
  FV_{t} = \sum_{d, m, s} N_{t}^{d,m,s} \, d_{t} \, F_{t} (s, m)
  \]
Data & institutional detail

- Call report derivatives data
  - notional
  - positive & negative fair values (marked to market)
  - "for trading" vs "not for trading"
  - maturity buckets

- Intermediation
  - large interdealer positions
  - dealers incorporate bid-ask spread into swap rates
  - data: bid-ask spreads (Bloomberg), net credit exposure (recent call reports)
  - subtract rents from intermediation from fair values, derive net notionals from trading on own account

- Unknown: directions of trade, locked in swap rates
Concentrated Holdings of Interest Rate Derivatives

Trillions $US

1995 2000 2005 2010

for trading
not for trading
top 3 dealers

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Data & institutional detail

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● Intermediation
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● Unknown: directions of trade, locked in swap rates
Gains from trade on own account

- Observation equation for "multiple" = fair value per dollar notional:

\[ \mu_t = d_t \ F_t (\bar{s}_t, \bar{m}_t) + \varepsilon_t \]

- Data
  - fair values (exclude intermediation rents)
  - net notionals
  - \( \bar{m}_t \) = average maturity
  - bond prices contained in \( F_t \)

- Estimation
  - prior over unknown sequence \( (d_t, \bar{s}_t) \)
  - measurement error \( \varepsilon \sim \mathcal{N} (0, \sigma_\varepsilon^2) \)
Observation equation for fair value per dollar notional:

\[ \mu_t = d_t F_t (\bar{s}_t, \bar{m}_t) + \varepsilon_t \]

- For each direction \( d_t \), can find swap rate to exactly match \( \mu_t \)
- For example, positive gains \( \mu_t > 0 \) require
  - pay fixed \( d_t > 0 \) & low locked-in rate \( \bar{s}_t \) than current rate \( s_t \)
  - pay floating \( d_t < 0 \) & high locked-in rate \( \bar{s}_t \) than current rate \( s_t \)

- Which is more plausible? Look at swap rate history!
Estimation details

- Fix $\text{var} (\varepsilon_t) = \text{var} (\mu_t) / 10$
- Compare two priors over sequence $(d_t, \bar{s}_t)$

1. Simple date-by-date approach
   - $\Pr (d_t = 1) = \frac{1}{2}$
   - prior over swap rate = empirical distribution over last 10 years
JP Morgan Chase: swap position

notionals

$ trillions

1995 2000 2005 2010
0 20 40 60

multiple $\mu_t$ (%)

1995 2000 2005 2010
-2 0 2 4

avg maturity swap rate (% p.a.)

2000 2005 2010
2 4 6
JP Morgan Chase: swap position

notionals

multiple $\mu_t$ (%)

posterior Pr(pay fixed)

avg maturity swap rate (% p.a.)
JPMorgan Chase: swap position

![Graphs showing JPMorgan Chase's swap position](image)

- **Notionals ($ trillions)**: Show the increase in notional values from 1995 to 2010.
- **Multiple $\mu_t$ (%)**: Illustrate the variation in multiple $\mu_t$ over the same period.
- **Posterior Pr(pay fixed)**: Display the probability distribution of paying fixed for the same years.
- **Avg maturity swap rate (% p.a.)**: Graph the average maturity swap rate from 2000 to 2010.
Estimation details

- Fix $\text{var} (\varepsilon_t) = \text{var} (\mu_t) / 10$
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1. Simple date-by-date approach
   - $\Pr (d_t = 1) = \frac{1}{2}$
   - prior over swap rate = empirical distribution over last 10 years

2. “Dynamic trading prior”
   - symmetric 2 state Markov chain for $d_t$ with prob of flipping $\phi = .1$
   - draw $s_0$ from empirical distribution
   - update swap rate conditional on evolution of $d_t$ and notionals
     a. increase exposure, same direction
        adjust swap rate proportionally to share of new swaps
     b. decrease exposure, same direction
        swap rate unchanged
     c. switch direction
        offset existing swaps & initial new position at current rate
JPMorgan Chase: swap position

### Notionals

- **$ trillions**
- **Years:** 1995, 2000, 2005, 2010
- **Graph:** Showing the trend of notionals over the years.

### Multiple $\mu_t$ (%)

- **Years:** 1995, 2000, 2005, 2010
- **Graph:** Showing the trend of multiple $\mu_t$ over the years with data and estimate lines.

### Posterior Pr(pay fixed)

- **Years:** 1995, 2000, 2005, 2010
- **Graph:** Showing the trend of posterior probability of pay fixed.

### Avg Maturity Swap Rate (% p.a.)

- **Years:** 2000, 2005, 2010
- **Graph:** Showing the trend of average maturity swap rate with different maturity and rate data estimates.
Summary

- Portfolio methodology to both measure and represent exposures in bank positions
- Results for top dealer banks
  Derivatives often increase exposure to interest rate risk.
- Possible models of banks
  - risk averse agents who use derivatives to insure (no!)
  - agents who insure others
    (bond funds? foreigners? those who don’t expect bailouts?)
- Next step: models with heterogeneous institutions, informed by position data represented as portfolios...