Princeton Initiative 2011
Macro, Money and Finance

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Motivation

- Aim: Bridge the gap between
  - Macro/money research
  - Finance research

- Financial sector helps to
  - overcome financing frictions and
  - channels resources
  - creates money

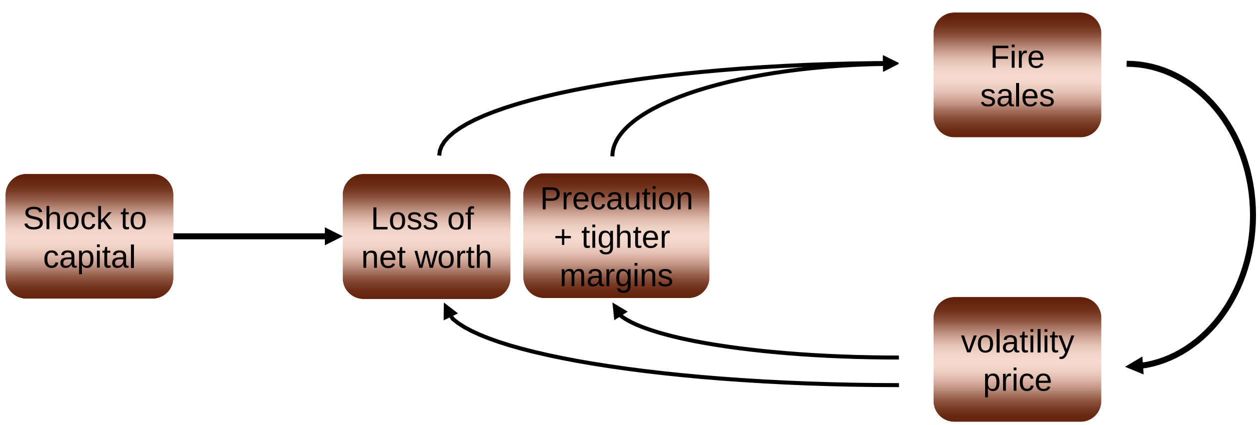
… but
  - Credit crunch due to
    adverse feedback loops & liquidity spirals
    - Non-linear dynamics
- New insights to monetary and international economics

Program overview http://www.princeton.edu/princeton_initiative

- Friday
  - Macro models with financial frictions in continuous time
  - Financial frictions: Empirical evidence
- Saturday
  - Demand for liquid assets, Money and Bubbles
  - Funding liquidity risk (rollover risk)
  - Bubbles
- Sunday
  - Fiscal Theory of the Price Level
  - International: Global Liquidity and Capital control

Systemic risk – a broad definition

- Systemic risk build-up during (credit) bubble
  … and materializes in a crisis
  - “Volatility Paradox” → contemp. measures inappropriate
- Spillovers/contagion – externalities
  - Direct contractual: domino effect (interconnectedness)
  - Indirect: price effect (fire-sale externalities)
    credit crunch, liquidity spirals



  - *Adverse GE response* ⇨ amplification, persistence

preventive

crisis management

Minsky moment – Wile E. Coyote Effect

Brunnermeier

Instruments

- Output (gap)

- Price stability
  Monetary policy
  - Short-term interest
  - Policy rule
    (terms structure)

inter-
action

- Financial stability
  Macroprudential policy
  - Reserve requirements
  - Capital/liquidity requiremts.
  - Collateral policy
    Margins/haircuts
  - Capital controls

Methodology

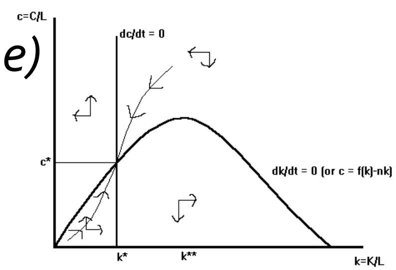
timeline

- *Verbal Reasoning* *(qualitative)*

  Fisher, Keynes, …

Macro

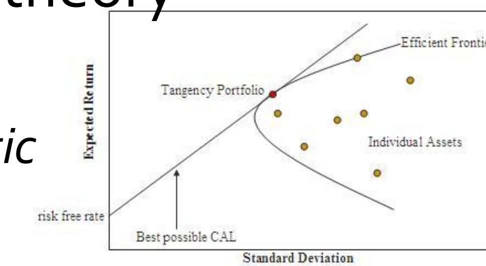
- Growth theory
  - *Dynamic (cts. time)*
  - *Deterministic*



- Introduce stochastic
  - *Discrete time*
    - Brock-Mirman, Stokey-Lucas
    - DSGE models

Finance

- Portfolio theory
  - *Static*
  - *Stochastic*



- Introduce dynamics
  - *Cts. time*
    - Option — Black Scholes
    - Term structure — CIR
    - Agency theory — Sannikov

- Cts. time macro with financial frictions

Brunnermeier

Heterogeneous agents + frictions

- Lending-borrowing/insuring since agents are different

▪ Poor-rich ▪ Productive ▪ Less patient ▪ Less risk averse ▪ More optimistic	← Limited direct lending due to frictions	▪ Rich-poor ▪ Less productive ▪ More patient ▪ More risk averse ▪ More pessimistic

- Friction → $p_s MRS_s$ different even after transactions
- **Wealth distribution matters!** (net worth of subgroups)
- **Financial sector is not a veil**

Liquidity Concepts

- Financial instability arises from the fragility of liquidity

A	L
Technological liquidity	**Funding liquidity**
- Reversibility of investment	- Maturity structure of debt
Market liquidity	- Can't roll over short term debt
- Specificity of capital Price impact of capital sale	- Sensitivity of margins
	- Margin-funding is recalled

~~Maturity~~ Liquidity mismatch

- The *liquidity mismatch* between assets and liabilities determines the severity of the amplification effects

Types of Funding Constraints

- Equity constraint
  - Skin in the game constraint — BruSan
- Debt constraints
  - Costly state verification a la Townsend — CF, BGG
  - Commitment problems/collateral constraints — KM, BP
    - Incomplete contracts a la Hart-Moore
    - Credit rationing a la Stiglitz-Weiss
    - Affected by
      - Price of collateral
      - Volatility of collateral

Liquidity – Persistence & Amplification

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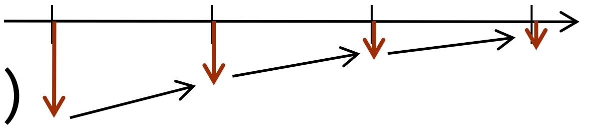
Structuring the Macro-literature on Frictions

1. Net worth effects:
   a. Persistence: Carlstrom, Fuerst
   b. Amplification: Bernanke, Gertler, Gilchrist
   c. Instability: Brunnermeier, Sannikov
2. Volatility effects: Credit quantity constraints
   a. Credit rationing: Stiglitz, Weiss
   b. Margin spirals : Brunnermeier, Pederson
   c. Endogenous constraints: Geanakoplos
3. Demand for liquid assets & Bubbles – "self insurance"
   a. OLG, Aiyagari, Bewley, Krusell-Smith, Holmstroem Tirole,…
4. Financial intermediaries & Theory of Money

Amplification & Instability - Overview

- Bernanke & Gertler (1989), Carlstrom & Fuerst (1997)
  - Perfect (technological) liquidity, but persistence
  - Bad shocks erode net worth, cut back on investments, leading to low productivity & low net worth of in the next period



- Kiyotaki & Moore (1997), BGG (1999)
  - Technological/market illiquidity
  - KM: Leverage bounded by margins; BGG: Verification cost (CSV)
  - Stronger amplification effects through prices (low net worth reduces leveraged institutions' demand for assets, lowering prices and further depressing net worth)
- Brunnermeier & Sannikov (2010)
  - Instability and volatility dynamics, volatility paradox
- Brunnermeier & Pedersen (2009), Geanakoplos
  - Volatility interaction with margins/haircuts (leverage)

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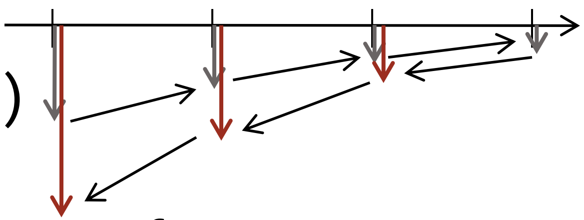

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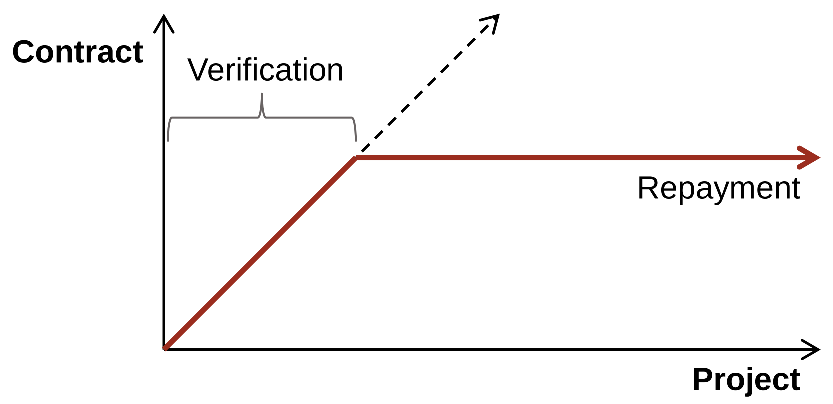
Persistence

- Even in standard real business cycle models, temporary adverse shocks can have long-lasting effects
- Due to feedback effects, persistence is much stronger in models with *financial frictions*
  - Bernanke & Gertler (1989)
  - Carlstrom & Fuerst (1997)
- Negative shocks to net worth exacerbate frictions and lead to lower capital, investment and net worth in future periods

Jump

Costly State Verification

- Key friction in previous models is costly state verification, i.e. CSV, a la Townsend (1979)
- Borrowers are subject to an idiosyncratic shock
  - Unobservable to lenders, but can be verified at a cost
- Optimal solution is given by a contract that resembles standard debt

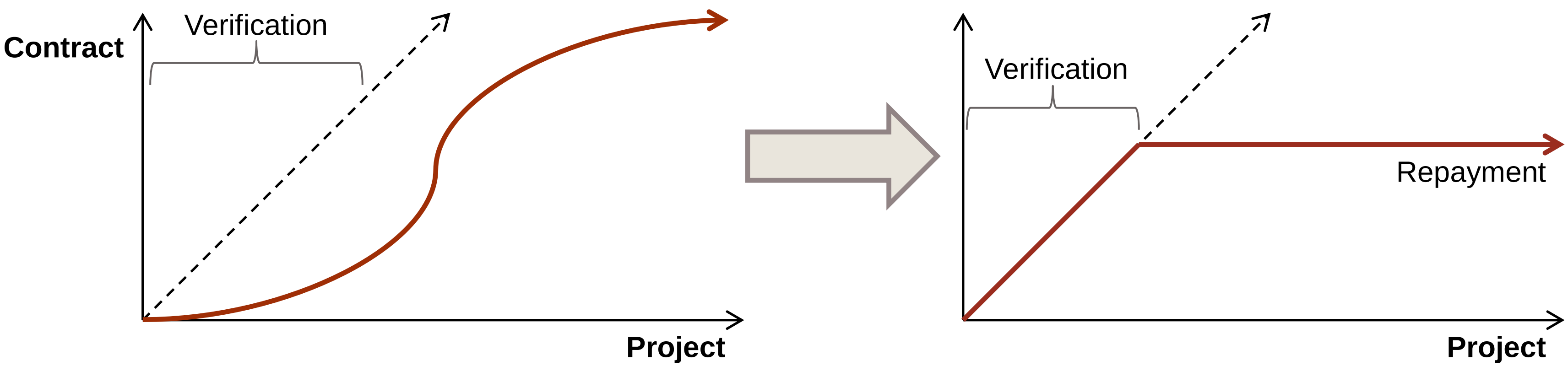


CSV: Contracting

- Competitive market for capital
  - Lender's expected profit is equal to zero
  - Borrower's optimization is equivalent to minimizing expected verification cost
- Financial contract specifies:
  - Debt repayment for each reported outcome
  - Reported outcomes that should be verified

CSV: Optimal Contract

- Incentive compatibility implies that
  - Repayment outside of VR is constant
  - Repayment outside of VR is weakly greater than inside
- Maximizing repayment in VR reduces the size and thus the expected verification cost



Brunnermeier

Carlstrom & Fuerst

- Output is produced according to $Y_t = A_t f(K_t)$
- Fraction η of entrepreneurs and $1 - \eta$ of households
  - Only entrepreneurs can create new capital from consumption goods
- Individual investment yields ωi_t of capital
  - Shock is given by $\omega \sim G$ with $E[\omega] = 1$
  - This implies consumption goods are converted to capital one-to-one in the *aggregate*
  - *No technological illiquidity!*

CF: Costly State Verification

- Households can verify ω at cost μi_t
  - Optimal contract is debt with audit threshold $\bar{\omega}$
  - Entrepreneur with net worth n_t borrows $i_t - n_t$ and repays $\min\{\omega_t, \bar{\omega}\} \times i_t$
- Auditing threshold is set by HH breakeven condition
  - $\left[\int_0^{\bar{\omega}} (\omega - \mu) dg(\omega) + \left(1 - G(\bar{\omega})\right)\bar{\omega}\right] i_t q_t = i_t - n_t$
  - Here, q_t is the price of capital
- No positive interest (within period borrowing) and no risk premium (no aggregate investment risk)

CF: Supply of Capital

- Entrepreneur's optimization:
  - $\max_{i_t} \int_{\bar{\omega}_t}^{\infty} (\omega - \bar{\omega}_t) dG(\omega)\, i_t q_t$
  - Subject to HH breakeven constraint
- Linear investment rule $i_t = \psi(q_t) n_t$
  - Leverage $\psi(q_t)$ is increasing in q_t
- Aggregate supply of capital is increasing in
  - Price of capital q_t
  - Aggregate net worth N_t

CF: Demand for Capital

- Return to holding capital:
  - $R_{t+1}^{k} = \frac{A_{t+1}f'(K_{t+1})+(1-\delta)q_{t+1}}{q_t}$
- Risk averse HH have discount factor $\underline{\beta}$
  - Standard utility maximization
  - Budget constraint:
    $c_t \leq A_t f'(K_t)k_t + q_t[(1-\delta)k_t - k_{t+1}]$
  - Euler equation: $u'(c_t) = \underline{\beta} E_t\left[R_{t+1}^{k} u'(c_{t+1})\right]$

Brunnermeier

CF: Demand for Capital

- Risk-neutral entrepreneurs are less patient, $\beta < \underline{\beta}$
  - Euler equation: $1 = \beta E_t\left[R^k_{t+1}\rho(q_t)\right]$
  - Return on internal funds:
    $\rho(q_t) \equiv \int_{\overline{\omega}_t}^{\infty}(\omega - \overline{\omega}_t)dG(\omega)\,\psi(q_t)q_t$
- Aggregate demand for capital is decreasing in q_t

CF: Persistence & Dampening

- Negative shock in period t decreases N_t
  - This increases financial friction and decreases I_t
- Decrease in capital supply leads to
  - Lower capital: K_{t+1}
  - Lower output: Y_{t+1}
  - Lower net worth: N_{t+1}
  - Feedback effects in future periods $t+2, \ldots$
- Decrease in capital supply also leads to
  - Increased price of capital q_t
  - Dampening effect on propagation of net worth shock

Dynamic Amplification

- Bernanke, Gertler and Gilchrist (1999) introduce *technological illiquidity* in the form of nonlinear adjustment costs to capital
- Negative shock in period t decreases N_t
  - This increases financial friction and decreases I_t
- In contrast to the dampening mechanism present in CF, decrease in capital supply leads to
  - Decreased price of capital due to adjustment costs
  - *Amplification* effect on propagation of net worth shock

Bernanke, Gertler & Gilchrist

- BGG assume separate investment sector
  - This separates entrepreneurs' capital decisions from adjustment costs
- $\Phi(\cdot)$ represents *technological illiquidity*
  - Increasing and concave with $\Phi(0) = 0$
  - $K_{t+1} = \Phi\left(\frac{I_t}{K_t}\right) K_t + (1-\delta)K_t$
- FOC of investment sector
  - $\max_{I_t}\{q_t K_{t+1} - I_t\} \Rightarrow q_t = \Phi'\left(\frac{I_t}{K_t}\right)^{-1}$

jump to KM97

BGG: Entrepreneurs

- Entrepreneurs alone can hold capital used in production
- At time t, entrepreneurs purchase capital for $t+1$
  - To purchase k_{t+1}, an entrepreneur borrows $q_t k_{t+1} - n_t$
  - Here, n_t represents entrepreneur net worth
- Assume gross return to capital is given by ωR^k_{t+1}
  - Here $\omega \sim G$ with $E[\omega] = 1$ and ω i.i.d.
  - R^k_{t+1} is the endogenous aggregate equilibrium return

BGG: Costly State Verification

- Entrepreneurs borrow from HH in a CSV framework
- If R_{t+1}^k is deterministic, then threshold satisfies:
  - $\left[(1-\mu)\int_0^{\bar{\omega}} \omega dG(\omega) + \big(1 - G(\bar{\omega})\big)\bar{\omega}\right] R_{t+1}^k q_t k_{t+1} = R_{t+1}(q_t k_{t+1} - n_t)$
  - Here, R_{t+1} is the risk-free rate
- If there is aggregate risk in R_{t+1}^k then BGG argue that entrepreneurs will insure HH against risk
  - This amounts to setting $\bar{\omega}$ as a function of R_{t+1}^k
  - As in CF, HH perfectly diversify against entrepreneur idiosyncratic risk

BGG: Supply of Capital

- Entrepreneurs solve the following problem:
  - $\max_{k_{t+1}} E\left[\int_{\bar{\omega}}^{\infty}(\omega-\bar{\omega})dG(\omega)\, R_{t+1}^{k} q_t k_{t+1}\right]$
  - Subject to HH breakeven condition (state-by-state)
- Optimal leverage is again given by a linear rule
  - $q_t k_{t+1} = \psi\left(\frac{E\left[R_{t+1}^{k}\right]}{R_{t+1}}\right) n_t$
  - In a log-linearized solution, the remaining moments are insignificant
- Aggregate capital supply is increasing in $E\left[R_{t+1}^{k}\right]$ and aggregate net worth N_t

BGG: Demand for Capital

- Return on capital is determined in a general equilibrium framework
  - Gross return to holding a unit of capital
  - $E\left[R^k_{t+1}\right] = E\left[\frac{A_{t+1}f'(K_{t+1})+q_{t+1}(1-\delta)+q_{t+1}\Phi\left(\frac{I_{t+1}}{K_{t+1}}\right)-\frac{I_{t+1}}{K_{t+1}}}{q_t}\right]$
- Capital demand is decreasing in expected return $E\left[R^k_{t+1}\right]$

BGG: Persistence & Amplification

- Shocks to net worth N_t are persistent
  - They affect capital holdings, and thus N_{t+1}, ...
- *Technological illiquidity* introduces amplification effect
  - Decrease in capital leads to reduced price of capital from $q_t = \Phi'\left(\frac{I_t}{K_t}\right)^{-1}$
  - Lower price of capital further decreases net worth

Kiyotaki & Moore 97

- Kiyotaki, Moore (1997) adopt a
  - collateral constraint instead of CSV
  - market illiquidity – second best use of capital
- Durable asset has two roles:
  - Collateral for borrowing
  - Input for production
- Output is produced in two sectors, differ in productivity
- Aggregate capital is fixed, resulting in extreme *technological illiquidity*
  - Investment is completely irreversible

Jump

KM: Amplification

- *Static* amplification occurs because fire-sales of capital from productive sector to less productive sector depress asset prices
  - Importance of *market liquidity* of physical capital
- *Dynamic* amplification occurs because a temporary shock translates into a persistent decline in output and asset prices

KM: Agents

- Two types of infinitely-lived risk neutral agents
- Mass η of productive agents
  - Constant-returns-to-scale production technology yielding $y_{t+1} = ak_t$
  - Discount factor $\beta < 1$
- Mass $1 - \eta$ of unproductive agents
  - Decreasing-returns-to-scale production $y_{t+1} = F(k_t)$
  - Discount factor $\underline{\beta} \in (\beta, 1)$

KM: Frictions

- Since productive agents are less patient, they will want to borrow b_t from unproductive agents
  - However, friction arises in that each productive agent's technology requires *his* individual human capital
  - Productive agents cannot pre-commit human capital
- This results in a collateral constraint $Rb_t \leq q_{t+1}k_t$
  - Productive agent will never repay more than the value of his asset holdings, i.e. collateral

KM: Demand for Assets

- Since there is no uncertainty, a *productive agent* will borrow the maximum quantity and will not consume any of the output
  - Budget constraint: $q_t k_t + b_t \leq (a + q_t)k_{t-1} - Rb_{t-1}$
  - Demand for assets: $k_t = \frac{1}{q_t - \frac{q_{t+1}}{R}}[(a + q_t)k_{t-1} - Rb_{t-1}]$
- Unproductive agents are not borrowing constrained
  - $R = \underline{\beta}^{-1}$ and asset demand is set by equating margins
  - Demand for assets: $R = \frac{F'(\underline{k}_t) + q_{t+1}}{q_t}$

Brunnermeier

KM: Equilibrium

- With fixed supply of capital, market clearing requires $\eta K_t + (1-\eta)\underline{K}_t = \bar{K}$
  - This implies $M(K_t) \equiv \frac{1}{R} F'\left(\frac{\bar{K}-\eta K_t}{1-\eta}\right) = q_t - \frac{1}{R} q_{t+1}$
  - Note that $M(\cdot)$ is increasing
- Iterating forward, we obtain: $q_t = \sum_{s=0}^{\infty} \frac{1}{R^s} M(K_{t+s})$

KM: Steady State

- In steady state, productive agents use tradable output a to pay interest on borrowing:
- This implies that steady state price q^* must satisfy:
  - $q^* - \frac{1}{R} q^* = a$
- Further, steady state capital K^* must satisfy:
  - $\frac{1}{R} F'\left(\frac{\overline{K} - \eta K^*}{1-\eta}\right) = a$
  - This reflects inefficiency since marginal products correspond only to *tradable* output

KM: Productivity Shock

- Log-linearized deviations around steady state:
  - Unexpected one-time shock that reduces production of all agents by factor $1 - \Delta$
- Change in assets for given change in asset price:
  - $\widehat{K}_t = -\frac{\xi}{1+\xi}\left(\Delta + \frac{R}{R-1}\hat{q}_t\right), \; \widehat{K}_{t+s} = \frac{\xi}{1+\xi}\widehat{K}_{t+s-1}$
  - $\frac{1}{\xi} = \frac{d \log M(K)}{d \log K}|_{K=K^*}$
- Reduction in assets comes from two shocks:
  - Lost output Δ
  - Capital losses on previous assets $\frac{R}{R-1}\hat{q}_t$

KM: Productivity Shock

- Change in price for given change in assets:
  - Log-linearize the equation $q_t = \sum_{s=0}^{\infty} \frac{1}{R^s} M(K_{t+s})$
  - This provides: $\hat{q}_t = \frac{1}{\xi} \frac{R-1}{R} \sum_{s=0}^{\infty} \frac{1}{R^s} \widehat{K}_{t+s}$
- Combining equations:
  - $\widehat{K}_t = -\left(1 + \frac{1}{(\xi+1)(R-1)}\right) \Delta$
  - $\hat{q}_t = -\frac{1}{\xi} \Delta$

KM: Static vs. Dynamic Amplification

- We can decompose the previous equations into static and dynamic multiplier effects
  - Static effect results from assuming $q_{t+1} = q^*$
- Static multiplier:
  - $\widehat{K}_t^s = -\Delta$
  - $\hat{q}_t^S = -\frac{(R-1)}{R}\frac{1}{\xi}\Delta$
- Dynamic multiplier:
  - $\widehat{K}_t^D = -\frac{1}{(\xi+1)(R-1)}\Delta$
  - $\hat{q}_t^D = -\frac{1}{R}\frac{1}{\xi}\Delta$

BruSan10: Instability & Non-Linear Effects

- Previous papers only considered log-linearized solutions around steady state
- Brunnermeier & Sannikov (2010) build a continuous time model to study full dynamics
  - Show that financial system exhibits inherent instability due to highly non-linear effects
  - These effects are asymmetric and only arise in the downturn
- Agents choose a *capital cushion*
  - Mitigates moderate shocks near steady state
  - High volatility away from steady state

Structuring the Macro-literature on Frictions

1. Net worth effects:
   a. Persistence: Carlstrom, Fuerst
   b. Amplification: Bernanke, Gertler, Gilchrist
   c. Instability: Brunnermeier, Sannikov
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Credit Rationing

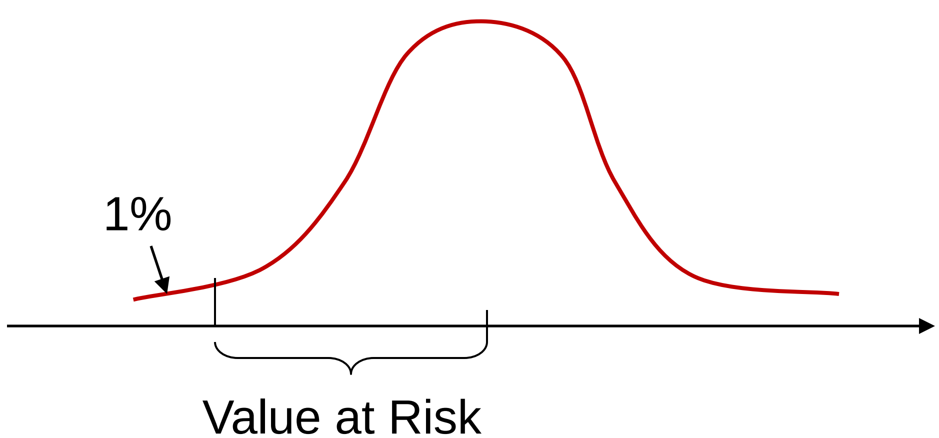
- Credit rationing refers to a failure of market clearing in credit
  - In particular, an excess demand for credit that fails to increase market interest rate
- Stiglitz, Weiss (1981) show how asymmetric information on risk can lead to credit rationing

Brunnermeier-Pedersen: Margin Spiral

- For collateralized lending, debt constraints are directly linked to the volatility of collateral
  - Constraints are more binding in volatile environments
  - Feedback effect between volatility and constraints
- These margin spirals force agents to delever in times of crisis
  - Collateral runs counterparty bank run
  - Multiple equilibria

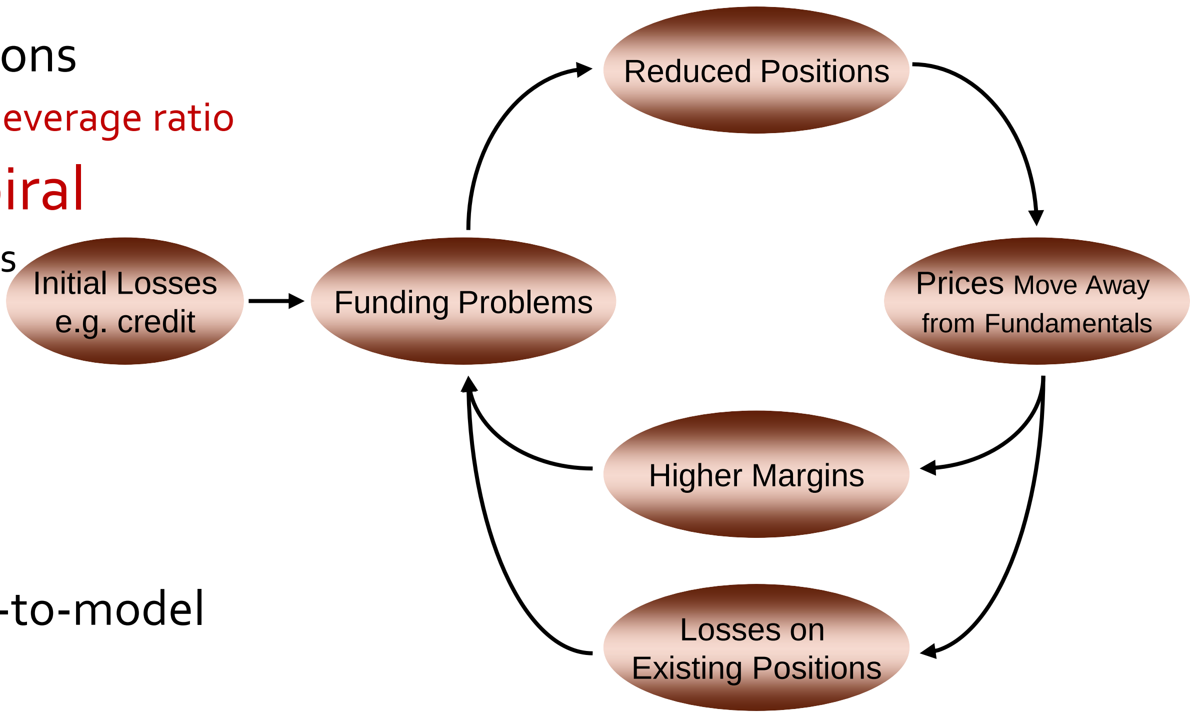
BP: Margins – Value at Risk (VaR)

- Margins give incentive to hold well diversified portfolio
- How are margins set by brokers/exchanges?
  - **Value at Risk**: $\Pr(-(p_{t+1} - p_t) \geq m) = 1\% = \pi$



BP: Liquidity Spirals

- Borrowers' balance sheet
  - Loss spiral – like in BGG/KM
    - Net wealth > α x
      for asym. info reasons
    - constant or increasing leverage ratio
  - Margin/haircut spiral
    - Higher margins/haircuts
    - No rollover
    - redemptions
    - forces to delever



Source: Brunnermeier & Pedersen (2009)

- Mark-to-market vs. mark-to-model
  - worsens loss spiral
  - improves margin spiral

• Both spirals reinforce each other

BP: Margin Spirals - Intuition

1. Volatility of collateral increases
   - Permanent price shock is accompanied by higher future volatility (e.g. ARCH)
     - Realization how difficult it is to value structured products
   - Value-at-Risk shoots up
   - Margins/haircuts increase = collateral value declines
   - Funding liquidity dries up
   - Note: all "expert buyers" are hit at the same time, SV 92
2. Adverse selection of collateral
   - As margins/ABCP rate increase, selection of collateral worsens
   - SIVs sell-off high quality assets first (empirical evidence)
   - Remaining collateral is of worse quality

BP: Model Setup

- Time: t=0,1,2
- One asset with final asset payoff v (later: assets j=1,…,J)
- Market illiquidity measure: $\Lambda_t=|E_t(v)-p_t|$

  (deviation from "fair value" due to selling/buying pressure)

- Agents
  - Initial customers with supply $S(z,E_t[v]-p_t)$ at t=1,2
  - Complementary customers' demand $D(z,E_2[v]-p_2)$ at t=2
  - Risk-neutral dealers provide *immediacy* and
    - face capital constraint
  - $xm(\sigma, \Lambda) \leq W(\Lambda) \quad := \quad \max\{0, \underbrace{B}_{\text{cash}} + \underbrace{x_0(E_1[v]-\Lambda)}_{\text{"price" of stock holding}}\}$

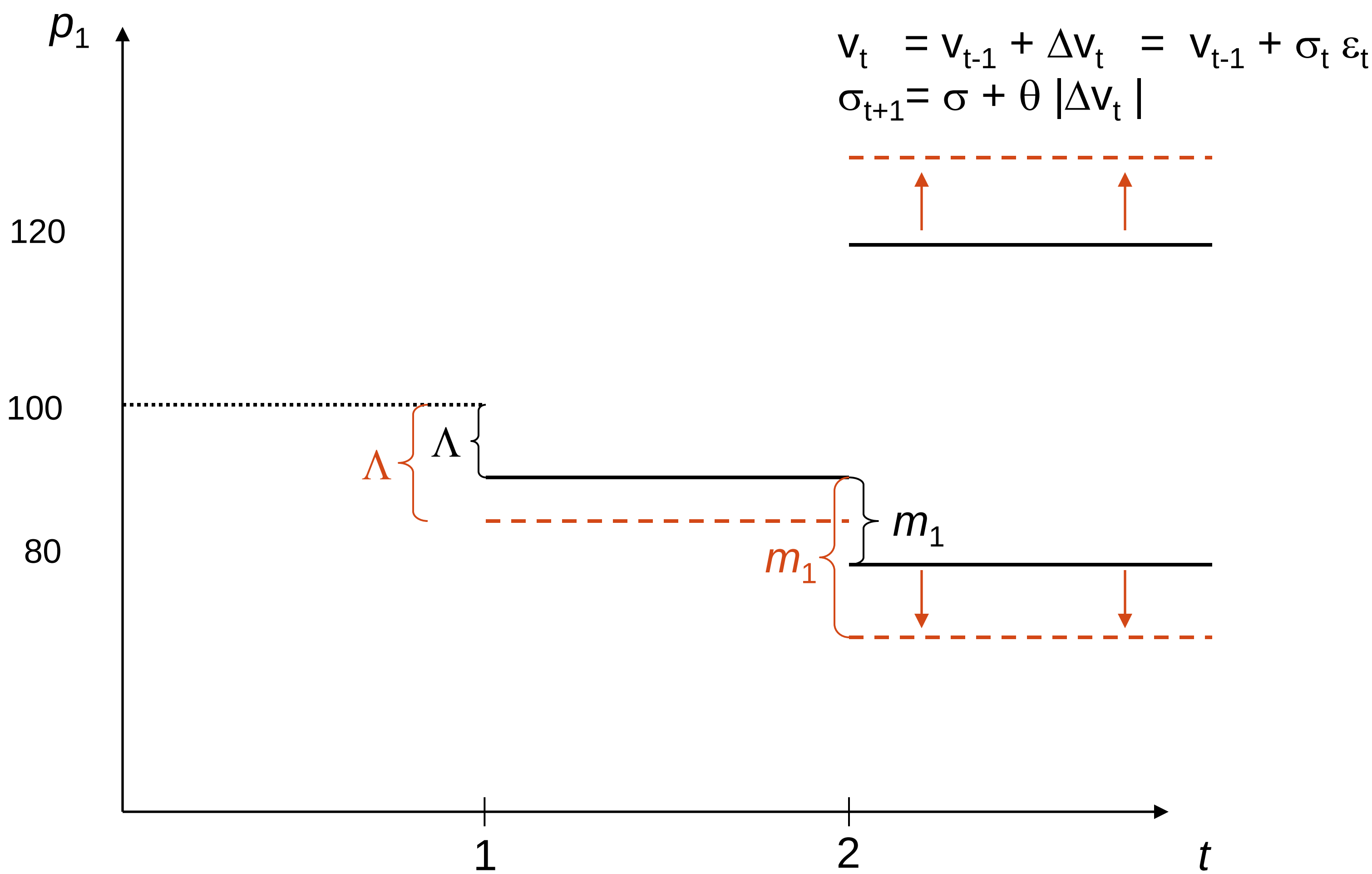
BP: Financiers' Margin Setting

- Margins are set based on Value-at-Risk
- Financiers do not know whether price move is due to
  - *Likely*, movement in fundamental
  - *Rare*, Selling/buying pressure by customers who suffered asynchronous endowment shocks.

$$m_1^{j+} = \Phi^{-1}(1-\pi)\sigma_2 = \bar{\sigma}^j + \bar{\theta}\left|\Delta p_1^j\right| = m_1^{j-}$$

Brunnermeier

BP: Margin Spiral – Increased Vol.



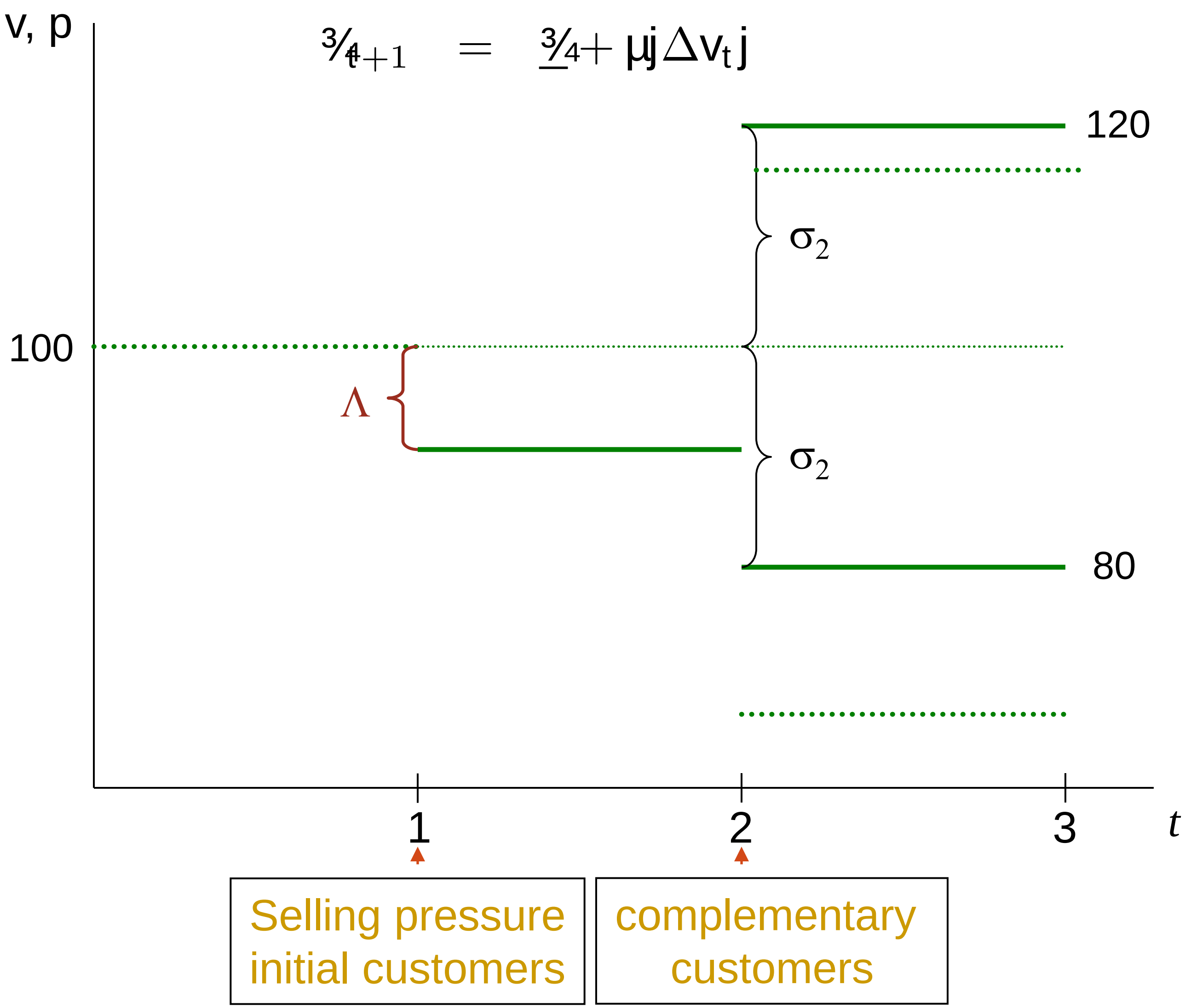
Selling pressure initial customers

complementary customers

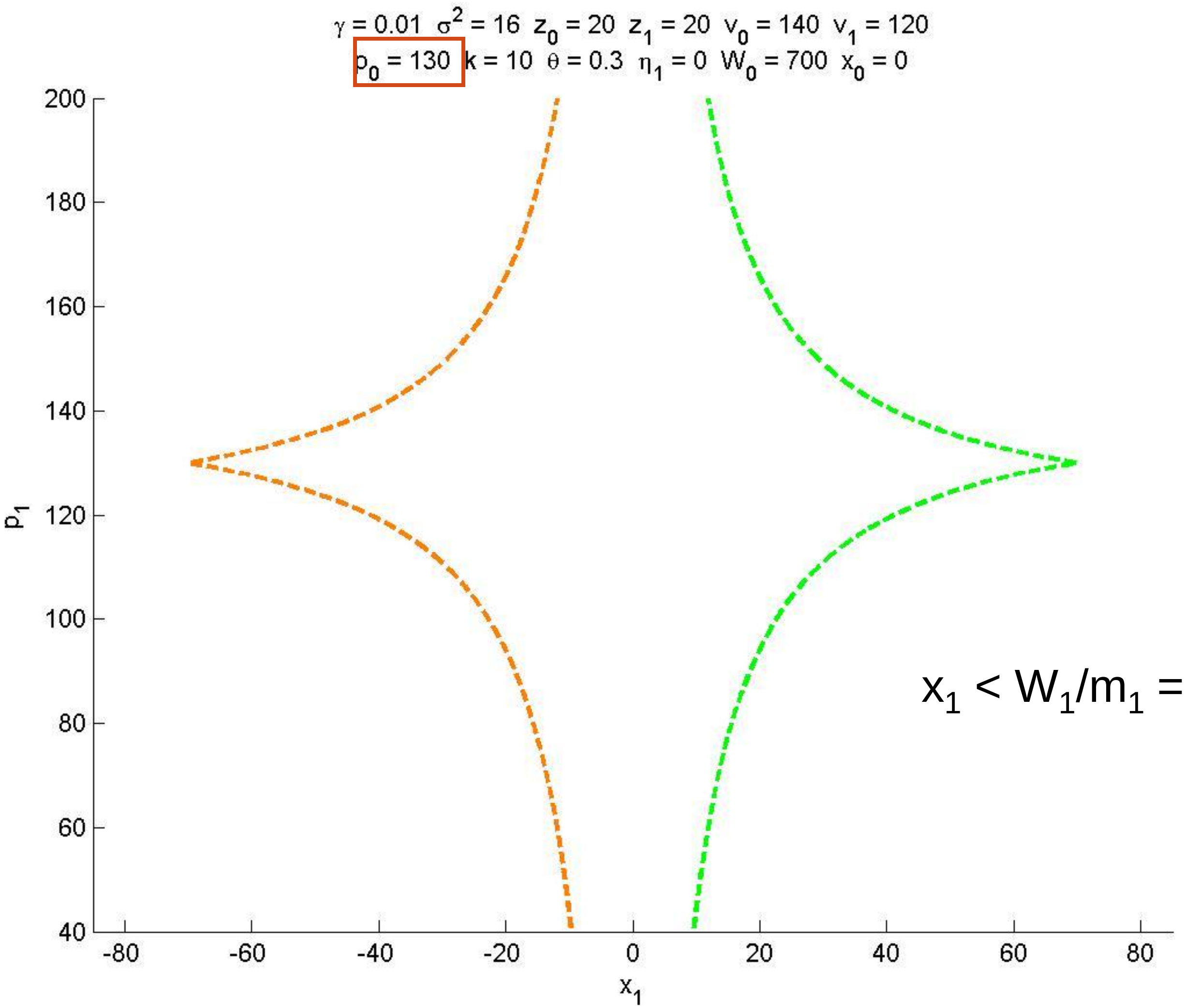
BP: Model Setup in a Figure

$v_t = v_{t-1} + \Delta v_t = v_{t-1} +$ ¾2 ¾4

¾$_{t+1}$ = ¾4 + µ j Δv_t j



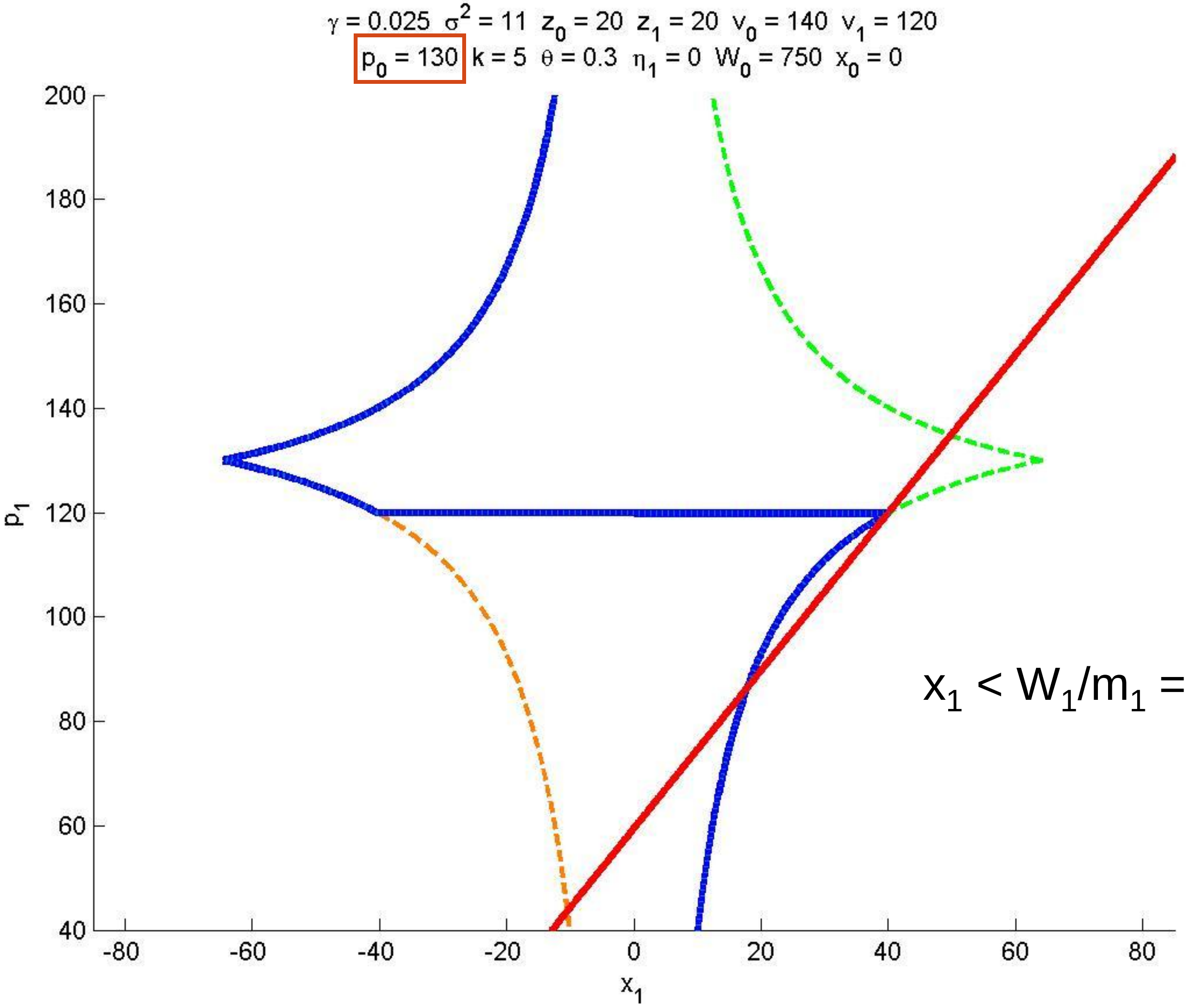
1. Margin Spiral – Increased Vol.



customers' supply

$x_1 < W_1/m_1 = W_1/(\sigma + \bar{\theta}|\Delta p_1|)$

1. Margin Spiral – Increased Vol.

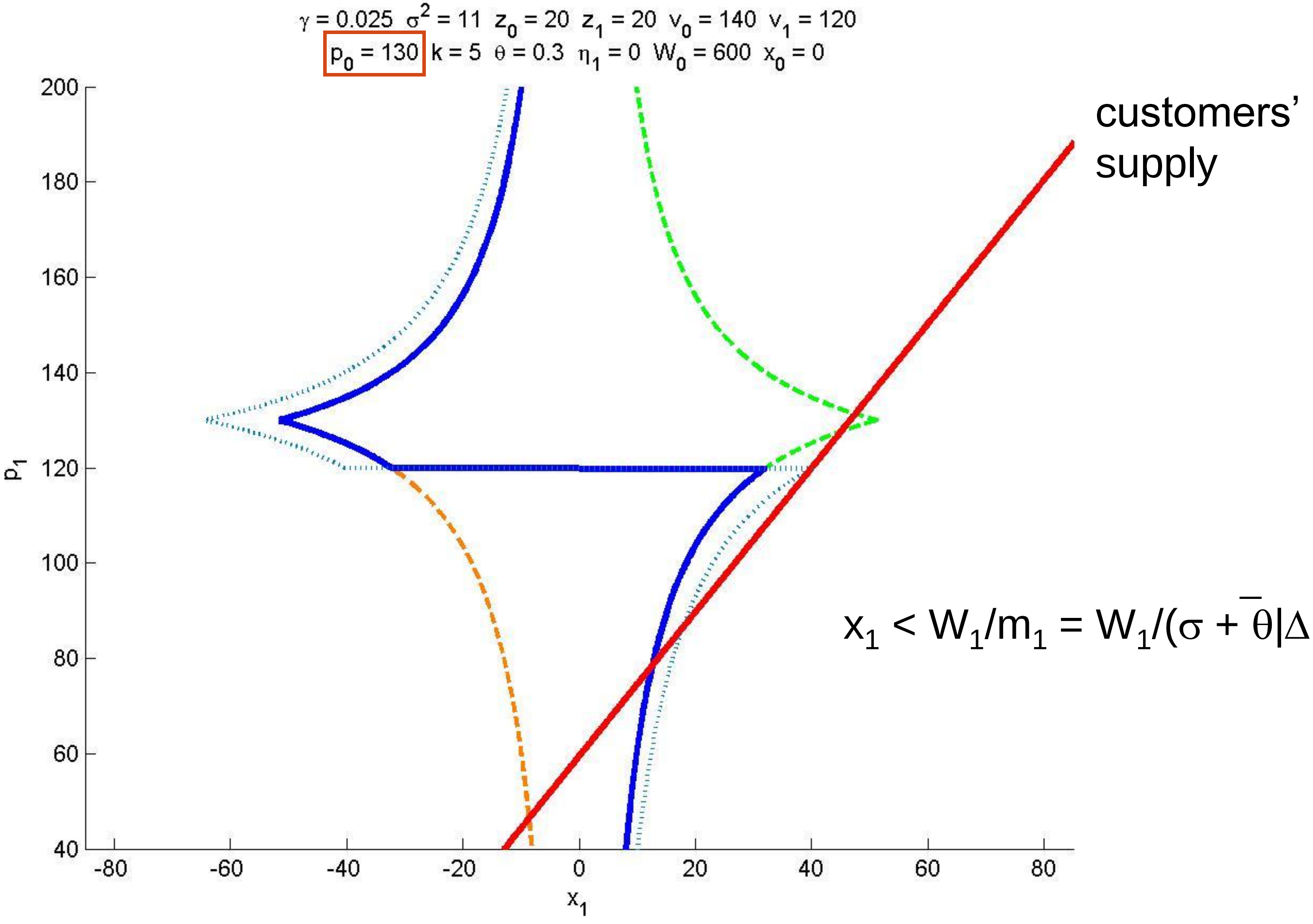


customers' supply

$x_1 < W_1/m_1 = W_1/(\sigma + \bar{\theta}|\Delta p_1|)$

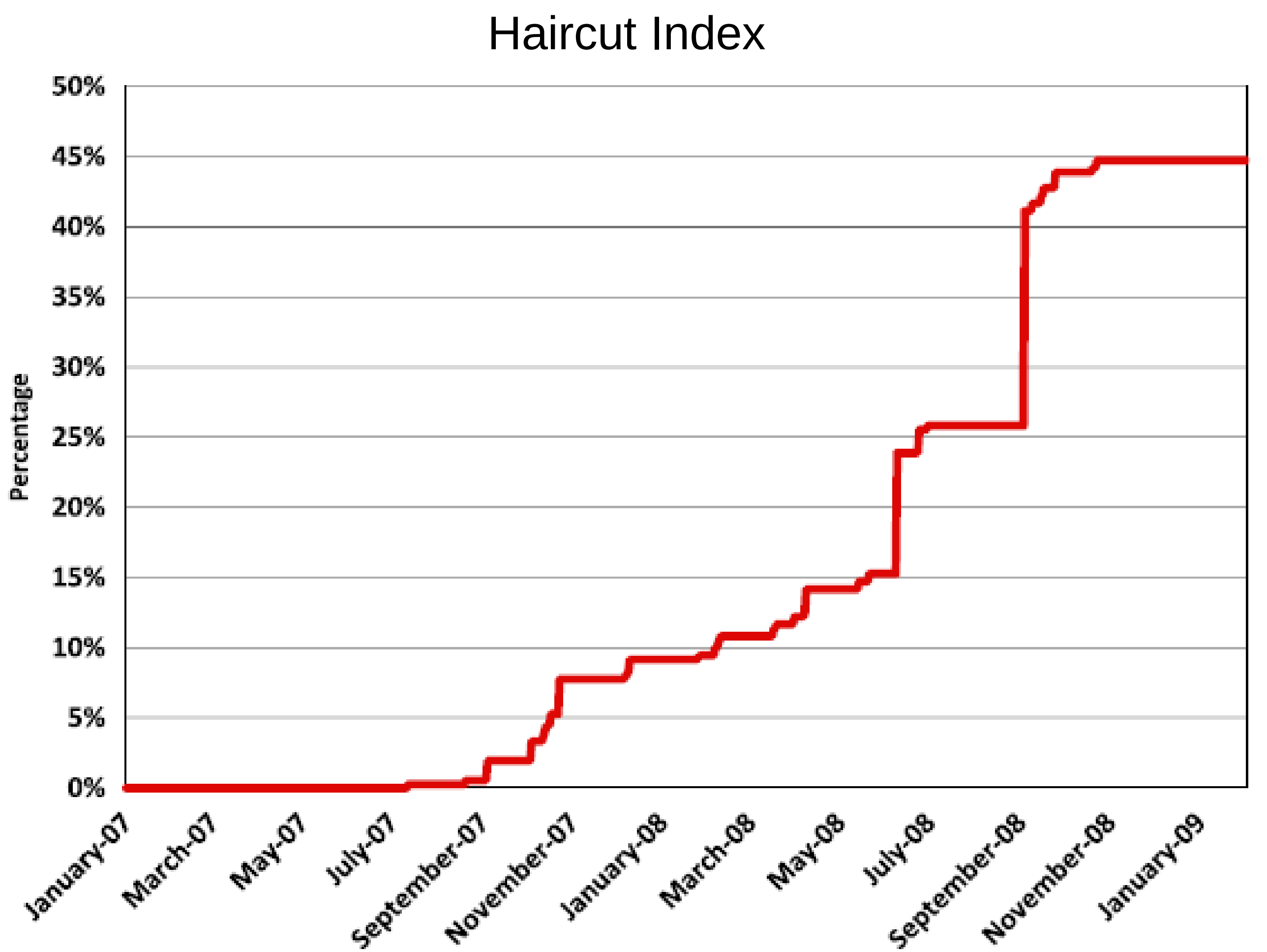
Brunnermeier

1. Margin Spiral – Increased Vol.



$x_1 < W_1/m_1 = W_1/(\sigma + \bar{\theta}|\Delta p_1|)$

Data Gorton and Metrick (2011)



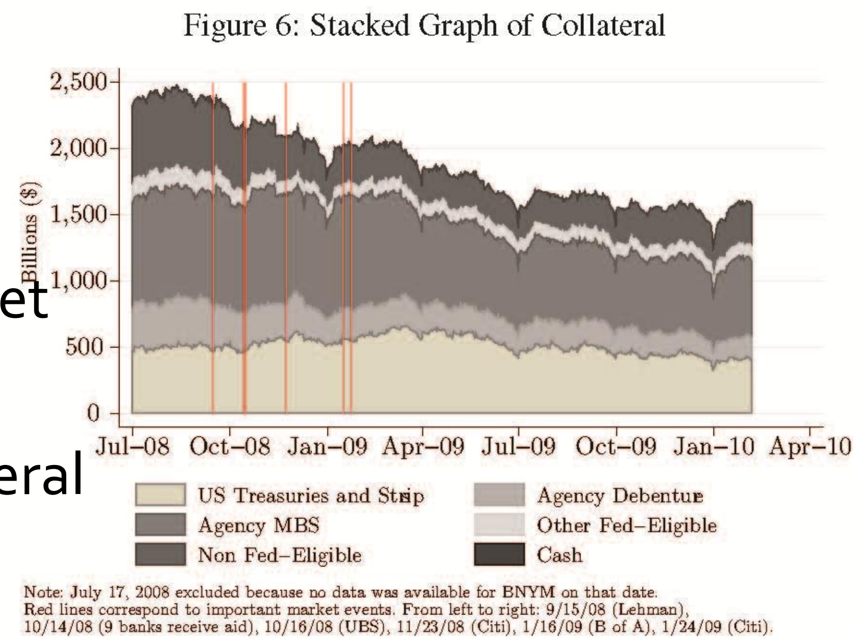
“The Run on Repo”

Brunnermeier

Copeland, Martin, Walker (2011)

Margins **stable** in tri-party repo market

- contrasts Gorton and Metrick
- no general run on certain collateral

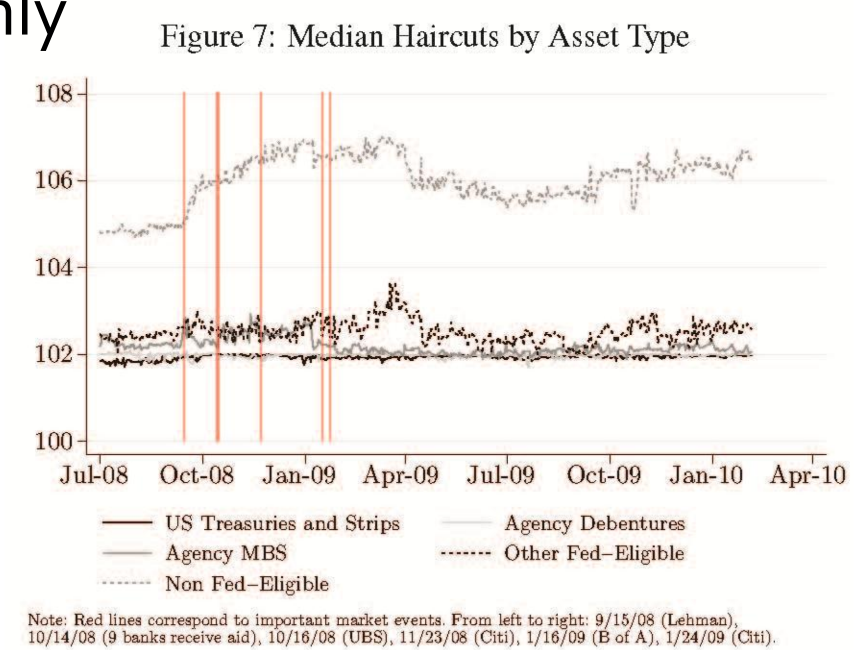


Run (non-renewed financing) only on select **counterparties**

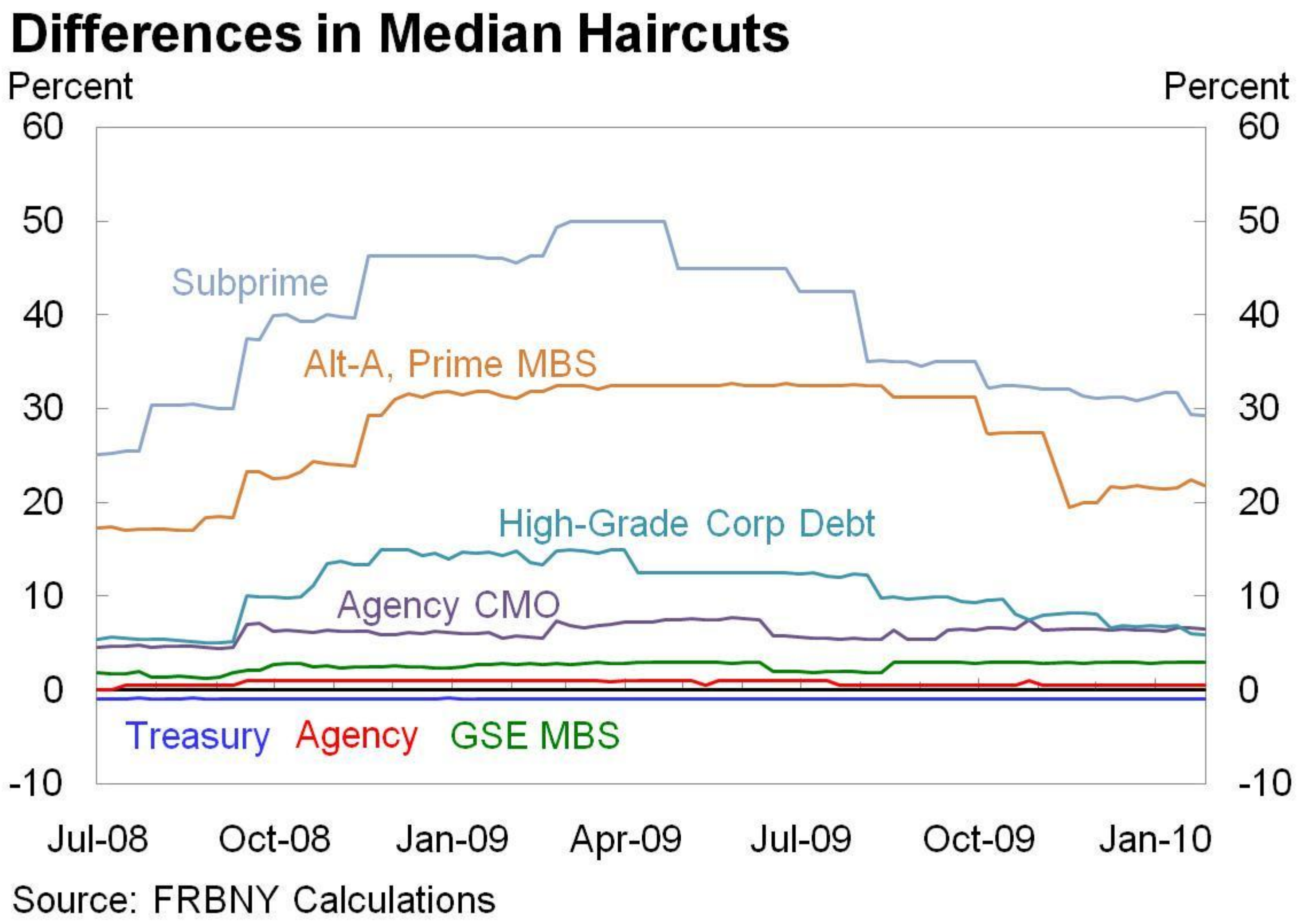
- Bear Stearns (anecdotally)
- Lehman (in the data)

Like 100% haircut…

(**counterparty specific!**)



Bilateral and Tri-party Haircuts?



Overview

1. Net worth effects:
   a. Persistence: Carlstrom, Fuerst
   b. Amplification: Bernanke, Gertler, Gilchrist
   c. Instability: Brunnermeier, Sannikov
2. Volatility effects: Credit quantity constraints
   a. Credit rationing: Stiglitz, Weiss
   b. Margin spirals : Brunnermeier, Pederson
   c. Endogenous constraints: Geanakoplos
3. Demand for liquid assets & Bubbles – "self insurance"
   a. OLG, Aiyagari, Bewley, Krusell-Smith, Holmstroem Tirole,…
4. Financial intermediaries & Theory of Money