Portfolio Theory w/ Settlement Frictions

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Big Picture & Agenda

- **Recent macro-finance:** convenience yields
  - Treasuries, Repo, FX markets
- **Convenience yields:** premia unexplained by cash flow (risk)
- **Agenda:** links convenience yields to
  - Supply of settlement instruments (e.g., reserves, debt)
  - OTC market frictions
- **Why Microfoundations?**
  1. Testable micro predictions: volumes, rates, dispersion
  2. Policy-relevance: non-invariant to policy
  3. Interaction with risk-aversion

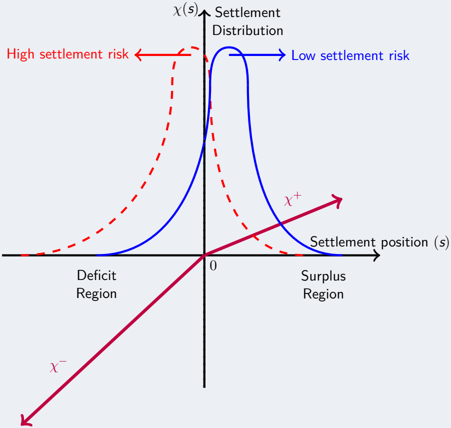
Preview of Mechanism

- Investors with portfolios
- Cash-flows: **settlement shocks** (e.g., deposits, margin calls)
- **Cash deficit:** borrow in **OTC market** or face penalty rate
- **Kinked convenience-yield function** of cash position s:

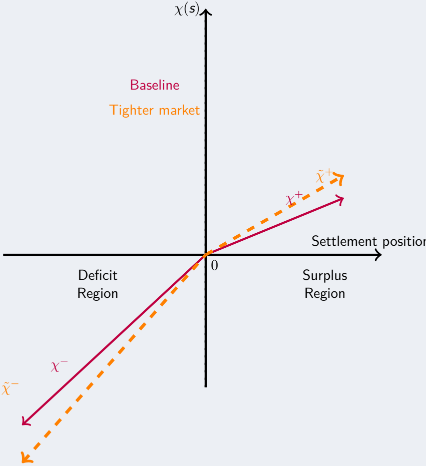
$$\chi(s) = \begin{cases} \chi^{-} s & \text{if } s < 0 \\ \chi^{+} s & \text{if } s \geq 0 \end{cases}$$

- χ^{-} and χ^{+} depend on:
  - market tightness $\theta = S^{-}/S^{+}$
  - matching technology $G, \bar{\lambda}$
  - bargaining power η

Preview of Mechanism



(a) Convenience yields



(b) Tightness and convenience yields

What we do here

- Afonso-Lagos ECMA '15
    - OTC market for Fed Funds
- Bianchi-Bigio ECMA '22
    - analytic OTC model (Leontief matching)
    - embedded in GE
    - study monetary policy
- Novelty here:
    - arbitrary assets (not only deposits)
    - generalize matching function
    - comparative statics convenience-yields
- Input in Recent work:
    - applications to exchange rates
    - optimal size of central-bank balance sheets

Contributions here

1. **Portfolio Theory:**
    - integrate OTC friction into rich asset choice/asset pricing framework
2. **OTC Market:**
    - formulas for trading rates & volumes for various cases
    - focus identification w/ micro data
3. **Asset Pricing:** theory of convenience yields
    - details how convenience yields vary with market structure/quantities
4. **Normative:** Identifies inefficient portfolio choices: guide regulation

Model Environment

- Infinite-horizon, unit mass of investors
- Asset return risk and **settlement risk**
- Trade in settlement instrument **frictional OTC market**
- Failure to borrow: penalty rate

Timeline: Two-Stages

1. **Portfolio Stage**
   - Choose holdings in assets $\{a^i\}$, $i \in \mathcal{I}$, and cash m
2. **Balancing Stage**
   - Idiosyncratic cash-flow shocks ω^i
   - Settlement in cash m
   - OTC trade: Borrow (or lend) from other investors f and or amount w at penalty (lender of last resort)

Asset Structure

- Assets $\{a^i\}_{i \in \mathbb{I}}$ differ in payoffs and liquidity properties
- Special asset m: riskless
- Constraint: must end each period $m \geq 0$

Cash-Flow Shocks and Surplus Definition

- At balancing stage, shocks ω^i perturb asset positions:

$$a^i_{t+1} = \tilde{a}^i_{t+1}(1 + \omega^i_t)$$

- Settlement surplus:

$$s = \tilde{m}_{t+1} + \sum_i \frac{R^i_{t+1}}{R^m_{t+1}} \omega^i_t \tilde{a}^i_{t+1}$$

- $s < 0$: deficit $\rightarrow$ needs funding
- $s > 0$: surplus $\rightarrow$ can lend or hold
- Examples: deposits, credit lines, margin calls, insurance claims, refinancing options, etc.

OTC trade

- Deficits funded via:
    - OTC market borrowing (probability Ψ_t^-)
    - At penalty (probability $1 - \Psi_t^-$)
- Surplus lent in OTC market (probability Ψ_t^+)
- Final cash holdings:

$$m_{t+1} = s + f_{t+1} + w_{t+1} \geq 0$$

Convenience Yields from Settlement Risk

- Total return includes direct asset return + settlement yield:

$$e_{t+1} = \sum_i R^i_{t+1} \tilde{a}^i_{t+1} + R^m_{t+1} \tilde{m}_{t+1} + \chi_{t+1}(s)$$

- Kinked convenience-yield function:

$$\chi_t(s) = \begin{cases} \chi^-_t s & \text{if } s < 0 \\ \chi^+_t s & \text{if } s \geq 0 \end{cases}$$

- Slopes depend on equilibrium OTC outcomes:

$$\chi^-_t = (\bar{R}^f_t - R^m_t)\Psi^-_t + (R^w_t - R^m_t)(1 - \Psi^-_t)$$

$$\chi^+_t = (\bar{R}^f_t - R^m_t)\Psi^+_t$$

- $\bar{R}^f_t$: average OTC rate, R^w_t: penalty rate
- Notation: r^x lower case for net rate

OTC Market Equilibrium: Matching Dynamics

- Afonso-Lagos block
- Define initial **aggregate** surplus and deficit:

$$S_0^+ = S^+, \quad S_0^- = S^-$$

- $n \in \mathcal{N} \equiv \{1, 2, ..., N\}$ rounds
- Round n, number of matches:

$$m_n = \lambda_N G(S_n^+, S_n^-)$$

- Surplus and deficit evolve as:

$$S_{n+1}^+ = S_n^+ - m_n, \quad S_{n+1}^- = S_n^- - m_n$$

Assumptions on Matching Function

Assume:

- **No disposal:** $G(0,1) = G(1,0) = 0$
- **Constant returns to scale:** Homogeneous degree one
- **Symmetry:** $G(a,b) = G(b,a)$
- **Weak exhaustion:** $\lambda_N G(S_n^+, S_n^-) \leq \min\{S_n^+, S_n^-\}$
- **Monotonicity:** $G_a, G_b \geq 0$
- **Weak concavity:** $G_{aa}, G_{bb} \leq 0$

Note: different in other models that assume IRS.

Tightness and Matching Probabilities

- Define market tightness:

$$\theta_n = \frac{S_n^-}{S_n^+}$$

- Matching probabilities for round n:

$$\psi_n^+ = \lambda_N G(1, \theta_{n-1}), \quad \psi_n^- = \lambda_N G(\theta_{n-1}^{-1}, 1)$$

- Convention: $\psi_{N+1}^{\pm} = 0$
- Equilibrium: $\psi_n^+ = \theta_{n-1}\psi_n^-$

Nash Bargaining in OTC Market

- **Trick:** investor delegates Δ trade sizes to traders
- In round n, traders bargain over $r_n^f = R_n^f - 1$:

$$r_n^f(\Delta) = \arg\max_{r_n} \left[\mathcal{S}_n^-(\Delta)\right]^\eta \left[\mathcal{S}_n^+(\Delta)\right]^{1-\eta}$$

- Surplus from trade (for deficit and surplus traders):

$$\mathcal{S}_n^- = V(\mathcal{E}^j(\Delta) - (r_n^f - r^m)\Delta) - J_U^-(n;\Delta)$$

$$\mathcal{S}_n^+ = V(\mathcal{E}^j(\Delta) + (r_n^f - r^m)\Delta) - J_U^+(n;\Delta)$$

- $\mathcal{E}^j(\Delta)$: "estimate" of investor equity, ex own trade

Limit Result: $\Delta \to 0$

- Infinitesimal trade: Shi '97 or Atkeson, Eisfeldt, Weill '15
- As trade size $\Delta \to 0$, trader's effect on equity becomes marginal:

$$V(e + \Delta x) \approx V(e) + V'(e) \cdot \Delta x$$

- Nash becomes:

$$\lim_{\Delta \downarrow 0} \left\{ \max_{r_n^f} \left[\mathcal{S}_n^-(\Delta)/\Delta \right]^\eta \left[\mathcal{S}_n^+(\Delta)/\Delta \right]^{1-\eta} \right\} =$$

$$V'\left(\mathcal{E}^j\right)^\eta V'\left(\mathcal{E}^k\right)^{1-\eta} \max_{r_n^f} \left[\chi_{n+1}^- - (r_n - r^m) \right]^\eta \left[(r_n - r^m) - \chi_{n+1}^+ \right]^{1-\eta}.$$

- Result: marginal utility V' factors out: outcome depends only on round n

Result: Infinitesimal Trade Bargaining

Dynamic Bargaining Problem

$$\max_{r_n^f \in \{r^m + \chi_n^+, r^m + \chi_n^-\}} \left(\chi_n^- - (r_n^f - r^m)\right)^\eta \left((r_n^f - r^m) - \chi_n^+\right)^{1-\eta}$$

Solution:

$$r_n^f = r^m + (1-\eta)\chi_n^- + \eta\chi_n^+$$

Difference Equation: χ_n^+ and χ_n^-

$$\chi_n^+ = (r_{n+1}^f - r^m)\psi_{n+1}^+ + \chi_{n+1}^+(1 - \psi_{n+1}^+)$$

$$\chi_n^- = (r_{n+1}^f - r^m)\psi_{n+1}^- + \chi_{n+1}^-(1 - \psi_{n+1}^-)$$

given $\chi_{N+1}^+, \chi_{N+1}^- = 0, = r^w - r^m$, $\{\psi_n^+, \psi_n^-\}$

Consistency

Proposition

Matching probabilities:

$$\Psi^- = 1 - \prod_{n=1}^{N}(1 - \psi_n^-), \quad \Psi^+ = 1 - \prod_{n=1}^{N}(1 - \psi_n^+)$$

Convenience yield slopes:

$$\chi^- = \Psi^-(\bar{r}^f - r^m) + (1 - \Psi^-)(r^w - r^m) = \chi_0^-$$
$$\chi^+ = \Psi^+(\bar{r}^f - r^m) = \chi_0^+$$

Rates: $\bar{r}^f$ is average rate across rounds weighted by volume

Algorithm: Convenience Yields

1. Forward iteration: compute $\{\psi_n^+, \psi_n^-\}$ using θ_0
2. Backward iteration: compute $\{\chi_n^+, \chi_n^-\}$ using terminal values
3. Then: $r_n^f = r^m + (1-\eta)\chi_n^- + \eta\chi_n^+$

Arrive at:

- $\chi_t^- = \chi_0^-$, $\chi_t^+ = \chi_0^+$ (slopes of liquidity yield)

Continuous-Time Limit

Limit $N \to \infty$, $\lambda_N \to 0$ with $N\lambda_N \to \bar{\lambda}$

- Trading rounds indexed by $\tau \in [0, 1]$.

ODE for market tightness

$$\dot{\theta}_\tau = \bar{\lambda}\theta_\tau \left[\gamma(1/\theta_\tau) - \gamma(\theta_\tau)\right], \quad \gamma(\theta) = G(1, \theta)$$

- Matching intensities:

$$\psi^+_\tau = \bar{\lambda}\gamma(\theta_\tau), \quad \psi^-_\tau = \bar{\lambda}\gamma(1/\theta_\tau)$$

Convenience Yields - Cont. Time Solution

Proposition

Given path of: $\{\psi^+, \psi^-\}$,

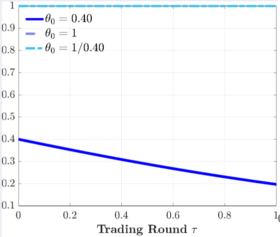
$$\chi_\tau^+ = (r^w - r^m) \int_\tau^1 (1-\eta)\psi_y^+ e^{-\int_y^1((1-\eta)\psi_x^+ + \eta\psi_x^-)dx} dy$$

$$\chi_\tau^- = (r^w - r^m) \left[1 - \int_\tau^1 \eta\psi_y^- e^{-\int_y^1((1-\eta)\psi_x^+ + \eta\psi_x^-)dx} dy\right]$$

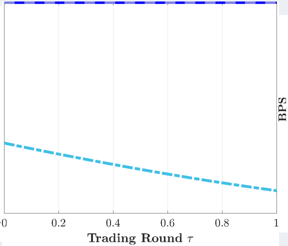
Bargaining Outcome still:

$$r_\tau^f = r^m + (1-\eta)\chi_\tau^- + \eta\chi_\tau^+$$

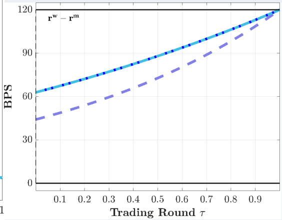
Example: Leontief Matching $G(a, b) = \min\{a, b\}$



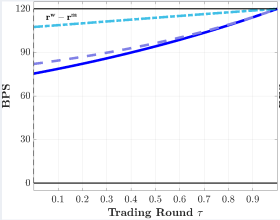
(a) Rate ψ^+



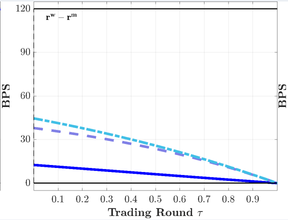
(b) Rates ψ^-



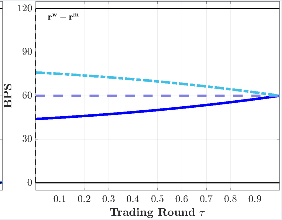
(c) Surplus Σ_τ



(d) Cost χ^-

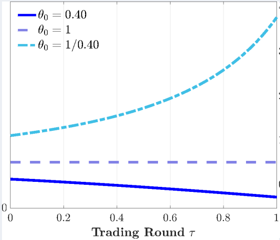


(e) Benefit χ^+



(f) Rate r_τ^f

Example: Cobb-Douglas $G(a, b) = \sqrt{a \cdot b}$



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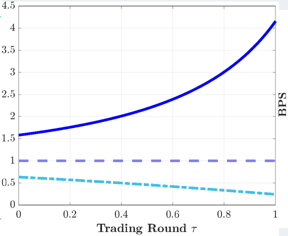
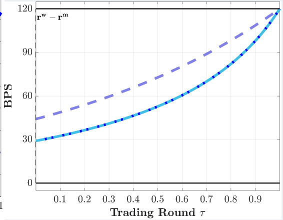


(b) Rates ψ^-



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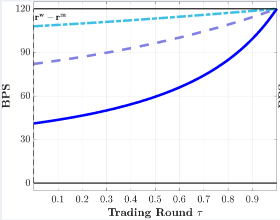
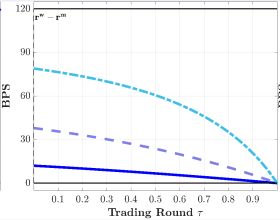


(d) Cost χ^-



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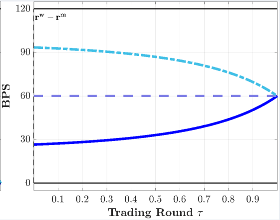


(f) Rate r^f_τ

Four Properties

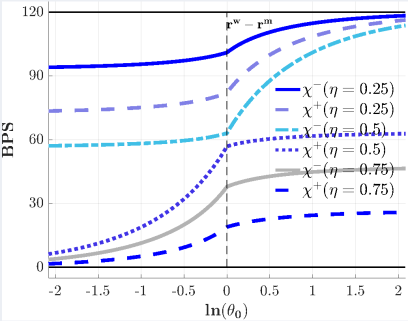
- **Balanced market** balanced market ($\theta_0 = 1$), stays balanced.
  - Exogenous trading probs.
- **Time Dilation** Dynamics from any point in session
  - Reset to full session, scale matching efficiency $\bar{\lambda}$ remaining time
- **Symmetry** Swapping deficit and surplus sides ($\theta \leftrightarrow \theta^{-1}$, $\eta \leftrightarrow 1 - \eta$)
  - mirrors yields around $r^w - r^m$
- **Bargaining Power** Borrower power ($\eta \uparrow$) lowers rates and yield coefficients
  - full borrower power $\Rightarrow \bar{r}^f = r^m$, viceversa

Efficiency Limits

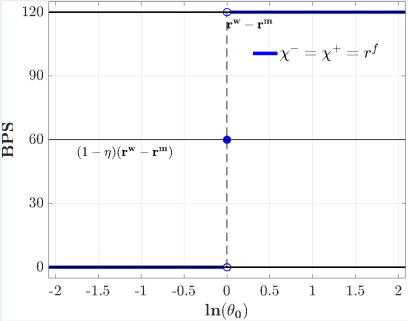
The OTC market equilibrium satisfies:

- **Walrasian Limit ($\bar{\lambda} \to \infty$)**
  - $\theta > 1$: $\Psi^+ = 1$, $\Psi^- = 1/\theta$, $\chi^+ = \chi^- = r^w - r^m$
  - $\theta < 1$: $\Psi^+ = \theta$, $\Psi^- = 1$, $\chi^+ = \chi^- = 0$
  - $\theta = 1$: $\Psi^+ = \Psi^- = 1$, $\chi^+ = \chi^- = (1-\eta)(r^w - r^m)$
- **Static Limit ($\bar{\lambda} \to 0$)**
  - $\Psi^+ = \Psi^- = 0$, $\chi^+ = 0$, $\chi^- = r^w - r^m$
  - $\bar{r}^f = r^m + (1-\eta)(r^w - r^m)$
- High efficiency leads to Walrasian outcomes
- Low efficiency: bargaining as in one round

Symmetry and Walrasian Limit



(a) Symmetry Property



(b) Walrasian Limit

Market Tightness

- $\chi^+, \chi^-, \bar{r}^f$ increasing in tightness θ
- What about extrema?

Proposition (Extrema of Market Tightness)

- $\theta \to 0$: $\chi^+ \to 0$, $\chi^- \to (r^w - r^m)e^{-\bar{\lambda}\bar{\gamma}\eta}$
- $\theta \to \infty$: $\chi^- \to r^w - r^m$, $\chi^+ \to (r^w - r^m)(1 - e^{-(1-\eta)\bar{\lambda}\bar{\gamma}})$

- **Key:** boundedness $\bar{\gamma} = \lim_{\theta \to 0} \gamma(\theta^{-1})$
- $\bar{\gamma}$ **finite:** yields/rates stay positive even as $\theta \to 0$

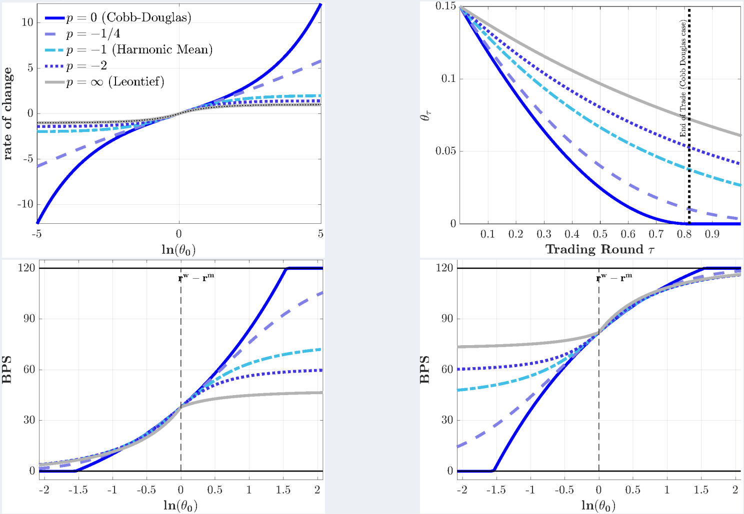
The CES Matching Class

- CES: $G(a, b) = (a^p + b^p)^{1/p}$, $p \leq 0$
- Within CES: Cobb-Douglas ($p = 0$) is knife-edge
  - Only matching function θ_τ can reach 0 in finite time
  - We care because Cobb-Douglas allows zero convenience yields

The CES Matching Class

(a) Growth rate of θ_τ

(b) Evolution of θ_τ



(c) χ^+

(d) χ^-

Tightness Formula: Cobb-Douglas vs. Leontief

Market Tightness $\theta(\tau)$

Feature	Cobb-Douglas ($p = 0$)	Leontief ($p = -\infty$)
$\theta(\tau)$	$\left(\frac{(1+\sqrt{\theta_0})e^{-\bar{\lambda}\tau}-(1-\sqrt{\theta_0})}{(1+\sqrt{\theta_0})e^{-\bar{\lambda}\tau}+(1-\sqrt{\theta_0})}\right)^2$	$\begin{cases} 1+(\theta_0-1)e^{\bar{\lambda}\tau}, & \theta_0 > 1 \\ \theta_0/(\theta_0+(1-\theta_0)e^{\bar{\lambda}\tau}), & \theta_0 < 1 \end{cases}$
Stop T	$\min\left\{\frac{1}{\bar{\lambda}}\log\left(\left\lvert\frac{1+\sqrt{\theta_0}}{1-\sqrt{\theta_0}}\right\rvert\right), 1\right\}$	∞
Ψ^+	$1-e^{-\bar{\lambda}T}\left(\frac{(1+\sqrt{\theta_0})+(1-\sqrt{\theta_0})e^{\bar{\lambda}T}}{(1+\sqrt{\theta_0})+(1-\sqrt{\theta_0})}\right)^2$	$\begin{cases} 1-e^{-\bar{\lambda}}, & \theta_0 \geq 1 \\ \theta_0(1-e^{-\bar{\lambda}}), & \theta_0 < 1 \end{cases}$
Ψ^-	$1-e^{-\bar{\lambda}T}\left(\frac{(1+\sqrt{\theta_0})-(1-\sqrt{\theta_0})e^{\bar{\lambda}T}}{(1+\sqrt{\theta_0})-(1-\sqrt{\theta_0})}\right)^2$	$\begin{cases} (1-e^{-\bar{\lambda}})\theta_0^{-1}, & \theta_0 > 1 \\ 1-e^{-\bar{\lambda}}, & \theta_0 \leq 1 \end{cases}$

Closed-Form: Yields and OTC Rate

Set $\bar{\theta} = \theta_1$ and $\theta = \theta_0$

Yield Coefficients and OTC Rate

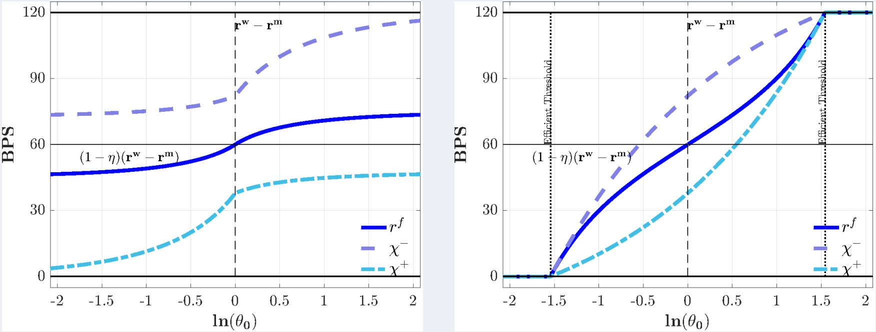
For both Cobb-Douglas and Leontief:

$$\chi^+ = (r^w - r^m)\left(\frac{\bar{\theta} - \bar{\theta}^\eta \theta^{1-\eta}}{\bar{\theta} - 1}\right), \quad \chi^- = (r^w - r^m)\left(\frac{\bar{\theta} - \bar{\theta}^\eta \theta^{-\eta}}{\bar{\theta} - 1}\right)$$

$$\bar{r}^f = \phi(\theta) r^m + (1 - \phi(\theta)) r^w, \quad \phi(\theta) = \frac{(\bar{\theta}/\theta)^\eta - \theta}{\bar{\theta}/\theta - 1}$$

- $\phi(\theta)$ acts as **endogenous bargaining index**
- Valid in closed-form only for $p = 0$ and $p = -\infty$
  - but not for all p

Cobb-Douglas vs. Leontief



(a) Frictional Case (Leontief) (b) Frictional Case (Cobb-Douglas)

- T takes care of making $\theta = 0$ of T<1

Portfolio Problem with Settlement Risk

Investor Preferences and Problem

Investor solves:

$$\max_{\{c,\tilde{a}^i_{t+1},\tilde{m}_{t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\gamma}-1}{1-\gamma}$$

subject to budget and return constraints.

- Cash return R^m and asset returns R^i are exogenous.
- Only OTC rate $\bar{R}^f$ and $\chi(s;\theta)$ endogenous
- Portfolio separation holds

Return on Portfolio and Risk

Portfolio Objective

Investor chooses weights to maximize equity return:

$$\max_{m,a^i} \left(\mathbb{E}\left[R^e\right]^{1-\gamma} \right)^{\frac{1}{1-\gamma}}$$

where:

$$R^e = \sum_i R^i a^i + R^m m + \chi\left(s(a^i, m, \omega); \theta\right)$$

- $\chi(s)$ is kinked: costly to be in deficit, modest benefit in surplus.
- s depends on portfolio weights and liquidity shocks.

Convenience Yields and Portfolio Premia

Decomposition of Excess Returns

At optimality:

$$\mathbb{E}[R^i] - R^m = \underbrace{-\mathbb{E}[\chi_s(\partial_m s - \partial_{a^i} s)]}_{\text{first-order liquidity yield}}$$
$$- \underbrace{\frac{\mathrm{Cov}[R_e^{-\gamma}, R^i + \chi_s(\partial_m s - \partial_{a^i} s)]}{\mathbb{E}[R_e^{-\gamma}]}}_{\text{total risk premium}}$$

- χ_s is the marginal convenience yield (χ^+ or χ^-).
- **Lesson:** premia reflect both mean liquidity effects and covariance with risk.
  - Risk and liquidity, not decoupled!
  - FX literature: assumes they are

Lessons for Portfolio Theory

Convenience yields:

- force toward determinate portfolios even under risk neutrality

Risk premia vs. convenience yield decompositions:

- not decoupled

Applications: Pricing anomalies

- short-term rate puzzle (Lenel-Piazzesi-Schneider)
- corporate-rate puzzle (Liao)
- CIP deviations (Krishnarmurthy-Jian-Lustig)
- deposit-rate heterogeneity (Dreschler-Savov-Schnabl)

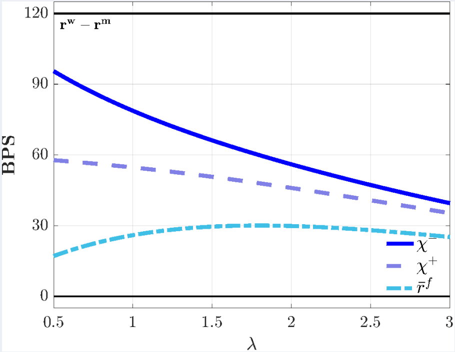
What Are We Trying to Identify?

Three Key Parameters

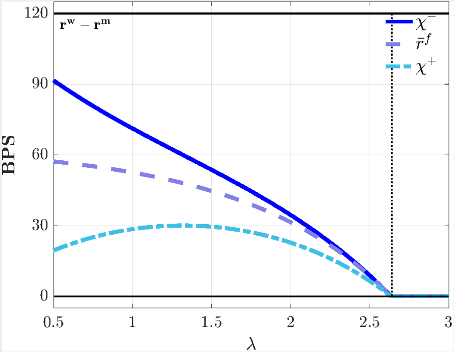
- Market tightness θ: imbalance between buyers and sellers
- Matching efficiency $\bar{\lambda}$: how quickly matches form
- Bargaining power η: who keeps the surplus

- Why identify them?
  - Decompose sources of convenience yields
  - Run policy or institutional counterfactuals
  - Map observed premia to underlying frictions

Non-Monotonicity: Identification Challenge



(a) Leontief Matching



(b) Cobb-Dogulas Matching

- Non monotonic yields in efficiency

Identification Strategy: Moments and Mapping

Observable Moments

- $\bar{r}^f$ and $\chi^{\pm} \Rightarrow$ pin down θ (monotonicity)
- Portfolios and implied $\theta \Rightarrow$ shock distribution Φ
- Intraday dispersion $Q \Rightarrow$ moment identify $\bar{\lambda}$ or G
- Relative volume $I(\theta) \equiv \frac{\Psi^-}{1-\Psi^-} \Rightarrow$ clean moment for $\bar{\lambda}$
- Use χ^+/χ^- near $\theta = 1 \Rightarrow$ infer η

Identification Strategy: Moments and Mapping

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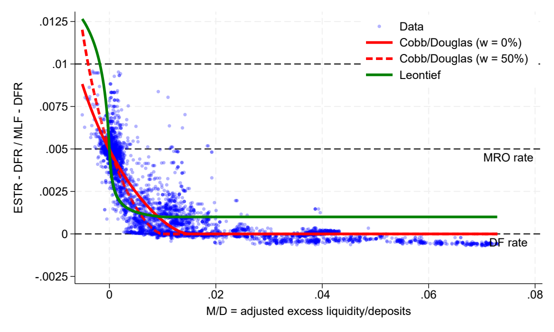
Payoff

- Estimate of $\frac{R^f - R^m}{R^w - R^m}$ as function of $\theta(M/D)$ for Euro Area
- Used in Bigio-Linzert-Mendo-Schumacher-Thaler:



Fit to Euro Area

Efficiency

- Portfolio choice may be constrained inefficient
- Depends on who earns penalties
- Here, assume it's waste

Banking Example: Withdrawal Risk

Portfolio Structure in Bianchi-Bigio '22

- Assets: cash m, illiquid bond b.
- Liability: deposit d subject to withdrawal shock ω.
- Settlement position:

$$s(b, d, m) = m + \left(\frac{R^d}{R^m}\omega - \rho(1+\omega) \right) d$$

- Budget: $b + m = 1 + d$.

Liquidity Premium on Bonds

Illiquid Asset vs. Cash

$$R^b - R^m = \chi^+ + (\chi^- - \chi^+)\tilde{\Phi}(\omega^*)$$

where:

$$\tilde{\Phi}(\omega^*) = \Phi(\omega^*) \cdot \frac{\mathbb{E}[R^e(\omega)^{-\gamma}|\omega < \omega^*]}{\mathbb{E}[R^e(\omega)^{-\gamma}]}, \quad \omega^* = \frac{\rho - m/d}{R^d/R^m - \rho}$$

- $\Phi(\omega^*)$: probability of cash deficit.
- $\tilde{\Phi}$: risk-adjusted deficit probability.

Efficiency of Portfolio Management

- Investors: not internalize effect on market tightness θ
- Externality: cash improves reduces external borrowing + but has opportunity cost
- Haider-Ismail and Zuniga
  - flipside, study loan-deposit wedge with rebate

Planner Problem

Planner Optimality Condition

$R^b - R^m = \chi^+ + (\chi^- - \chi^+)\tilde{\Phi}(\omega^*) + H$

- H: pecuniary externality from m's effect on θ and χ.
- Planner internalizes how m affects matching and yields.

Direction of the Externality

- Risk-neutrality ($\gamma \to 0$), planner values cash more iff

$$\frac{\partial \chi^+}{\partial \theta} S^+ > \frac{\partial \chi^-}{\partial \theta} S^-$$

Cases: Leontief vs. Cobb-Douglas

- Cobb-Douglas:
  - near balanced market ($\theta = 1$), no inefficiency.
  - risk-aversion: force toward more liquidity $m \Rightarrow$ precautionary motive
- Leontief:
  - matching probabilities of short-side fixed
  - no inefficiency if planner & market allocation feature aggregate surplus
- Inefficiencies: matching-function specific

Policy Implications

- Inefficiency: liquidity regulation
- Planner: more cash to reduce exposure to costly borrowing (e.g., FX reserve management, Central Bank balance sheet)

Limitations and Extensions

- Results rely on simplifying assumptions
  - large number of traders, no network, no effort
- Portfolio: one layer. Reality: multi-layered.
- **Still, useful to know simplest outcomes**

Thank You!

Questions, comments?