Settlement Speed and Financial Stability

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Motivation

- There has been a trend of faster settlement speed:
  - SEC T+1 settlement (effective May 28, 2024)
  - Real-time payment systems (FedWire, FedNow, RTP)
  - Faster deferred net settlement (e.g., CHIPS)

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  - Banks increased liquid asset holdings
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  - Banks increased liquid asset holdings
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  - **Tradeoff**: convenience vs. ability to delay and net payments
- **Research Question:** Does faster settlement improve or worsen financial stability?

Our Contribution

- Novel network model with **time dimension**:
  1. Networked payment flows
  2. Netting of obligations
  3. Liquidity costs
  4. Counterparty defaults

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- **Key insight:** Faster settlement reduces likelihood, but increases severity of systemic events

- **Main findings:**
  - Discontinuous contagion patterns
  - Default threshold points critical for welfare
  - Network structure matters
  - Liquidity conditions determine optimal settlement speed

Related Literature 1/2

- Financial Networks:
  Eisenberg and Noe (2001), Rogers and Veraart (2013), Elliott, Golub, and Jackson (2014), Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015), Glasserman and Young (2015), Bernard, Capponi, and Stiglitz (2022), Capponi, Corell, and Stiglitz (2022), Donaldson, Piacentino, and Yu (2022), Jackson and Pernoud (2024), Chang and Chuan (2024, 2025)

- Settlement speed and impatience vs costly borrowing:
  Khapko and Zoican (2020)

- Portfolio compression and netting:
  D'Errico and Roukny (2021), Chang (2021), Veraart (2022)

Related Literature 2/2

- Payment systems and liquidity cost:
  VanHoose and Sellon Jr (1989), Rochet and Tirole (1996), Hancock and Wilcox (1996), McAndrews and Rajan (2000), Kahn, McAndrews, and Roberds (2003), Mills Jr and Nesmith (2008), Afonso and Shin (2011)
- RTGS vs DNS:
  Copeland and Garratt (2019), Ding, Gonzalez, Ma, and Zeng (2025)
- Liquidity cost and trades:
  Brunnermeier and Pedersen (2009), Acharya and Merrouche (2013), Andolfatto (2020)
- Role of netting efficiency:
  Duffie and Zhu (2011), Carapella and Mills (2011), Duffie, Scheicher, and Vuillemey (2015), Capponi, Wang, and Zhang (2022)

Model Overview

- **Agents:** n agents with
  - Assets: Cash buffer $\bar{e}$ and payments received from other agents
  - Liabilities: Senior debt $\bar{s}$ and payments to other agents
- **Payment network:** Adjacency matrix $D \equiv [d_{ij}]_{i,j \in N}$,
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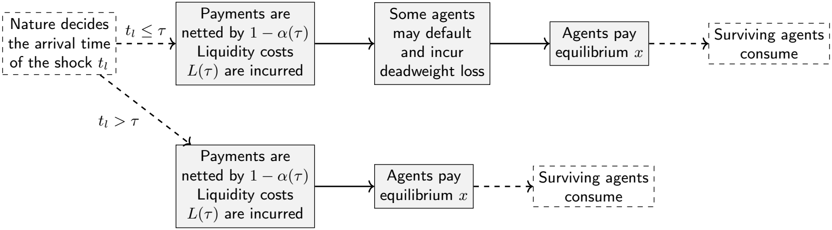
- **Defaults:** Payment shortfalls create deadweight losses $\beta\xi_j$

Timeline



Nature decides the arrival time of the shock t_l
$t_l \leq \tau$
Payments are netted by $1-\alpha(\tau)$ Liquidity costs $L(\tau)$ are incurred
Some agents may default and incur deadweight loss
Agents pay equilibrium x
Surviving agents consume
$t_l > \tau$
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Agents pay equilibrium x
Surviving agents consume

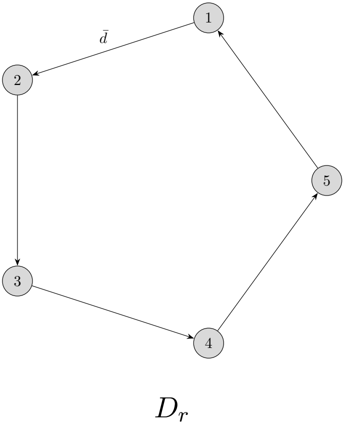
Ex Ante Social Welfare Loss

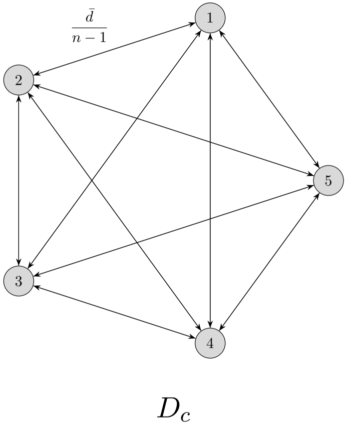
- Ex ante welfare loss:

$$W(\tau, D) = \sum_{i \in N} \left(\underbrace{L(\tau)}_{\substack{\text{liquidity} \\ \text{cost}}} + \underbrace{F(\tau)}_{\substack{\text{shock} \\ \text{prob}}} \quad \underbrace{E[\beta \xi_j]}_{\substack{\text{expected} \\ \text{deadweight loss}}} \right)$$

- **Tradeoff:**
  - Faster $\tau \Rightarrow$ Higher $L(\tau)$, less netting, but lower $F(\tau)$
  - Slower $\tau \Rightarrow$ Lower $L(\tau)$, more netting, but higher $F(\tau)$
- What about the expected deadweight loss?

Ring vs Complete Network





Ex Post Phase Transition (Proposition 1)

For shock threshold $\epsilon^*(\tau) = n(\bar{e} - \bar{s} - L(\tau))$ and liability threshold $d^*(\tau) = (n-1)(\bar{e} - \bar{s} - L(\tau))$, **conditional on shock arrival**:

Complete network:

- If $\bar{\epsilon} \leq \epsilon^*(\tau)$ or $\alpha(\tau)\bar{d} \leq d^*(\tau)$: only 1 agent defaults
- If both thresholds exceeded: all agents default

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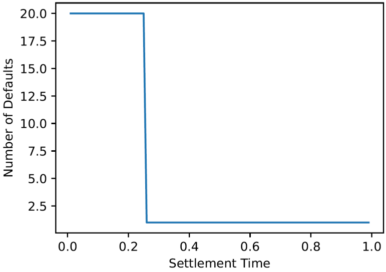
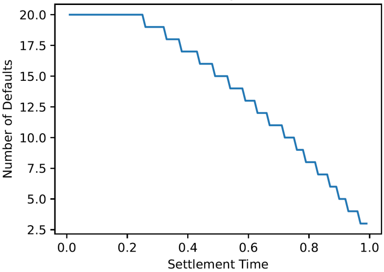
Ring network:

- Below thresholds: multiple defaults (more than complete)
- Above thresholds: all default with **higher total deadweight loss**

Contagion Patterns: Conditional on Shocks



(a) Complete: Phase transition



(b) Ring: Gradual increase

Threshold Point (Corollary 1)

All agents default in complete network iff $\tau \leq \tau^*$, where:

$$L(\tau^*) = \bar{e} - \bar{s} - \min\left\{\frac{\bar{\epsilon}}{n}, \frac{\alpha(\tau^*)\bar{d}}{n-1}\right\}$$

Implications:

- Threshold τ^* decreases in net cash buffer $\bar{e} - \bar{s}$
- Interaction between liquidity cost ($L(\tau)$) and netting efficiency ($\alpha(\tau)$) determines threshold
- Greater netting allows faster settlement without full contagion

Ex Ante Welfare (Proposition 2)

For $\tau \leq \tau^*$ (below threshold):

$$\frac{\partial W(\tau, D_c)}{\partial \tau} < \frac{\partial W(\tau, D_r)}{\partial \tau}$$

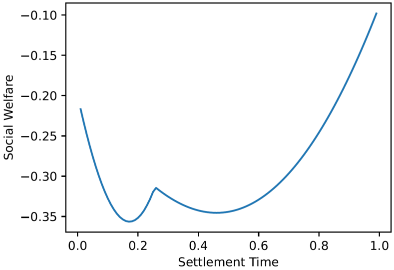
Implication: Marginal change in τ can:

- Improve welfare for complete network

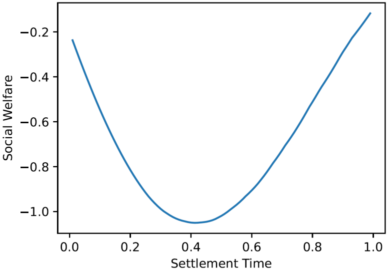
- Worsen welfare for ring network

$\Rightarrow$ **Network structure critically affects optimal settlement speed**

Ex Ante Welfare Comparison



(a) Complete: Kink at threshold



(b) Ring: Smooth changes

Welfare Decomposition (Proposition 3)

For constant default set, marginal welfare effect:

$$\underbrace{\underbrace{nL'(\tau)}_{\substack{\text{decrease in}\\ \text{liquidity cost}}} + \underbrace{F(\tau)}_{\substack{\text{probability of}\\ \text{shock arrival}}} \underbrace{\sum_{j \in \mathcal{D}(\tau,\epsilon)} \beta \frac{\partial \xi_j(\tau, D, \epsilon)}{\partial \tau}}_{\substack{\text{decrease in aggregate}\\ \text{deadweight loss}}}}_{\text{Benefit}} + \underbrace{\underbrace{F'(\tau)}_{\substack{\text{increased likelihood}\\ \text{of shock arrival}}} \underbrace{\sum_{j \in \mathcal{D}(\tau,\epsilon)} \beta \xi_j(\tau, D, \epsilon)}_{\substack{\text{aggregate}\\ \text{deadweight loss}}}}_{\text{Cost}}.$$

Trade-off depends on:

- Liquidity cost function $L(\tau)$
- Netting efficiency $\alpha(\tau)$
- Shock arrival rate $F(\tau)$
- Network structure (through ξ_j)

Default Threshold Points (Theorem 1)

Definition: $\tau \in \mathcal{T}(D)$ where marginal decrease in τ increases defaults

Theorem 1: At settlement speed thresholds,

$$\frac{\partial W(\tau, D)}{\partial \tau^-} < \frac{\partial W(\tau, D)}{\partial \tau^+}$$

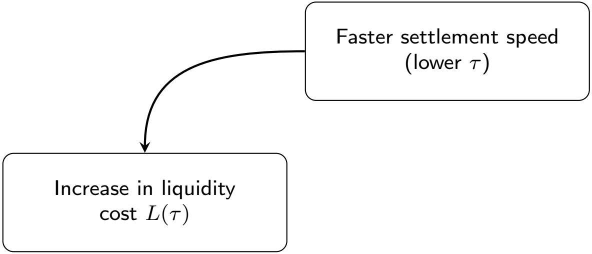
Implication:

- Discrete jumps in welfare at thresholds
- Must account for discontinuities in welfare analysis
- Can improve welfare by increasing τ at threshold

Impact of Faster Settlement Speed

Faster settlement speed
(lower τ)

Impact of Faster Settlement Speed



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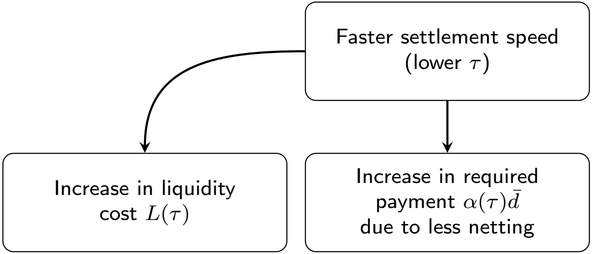

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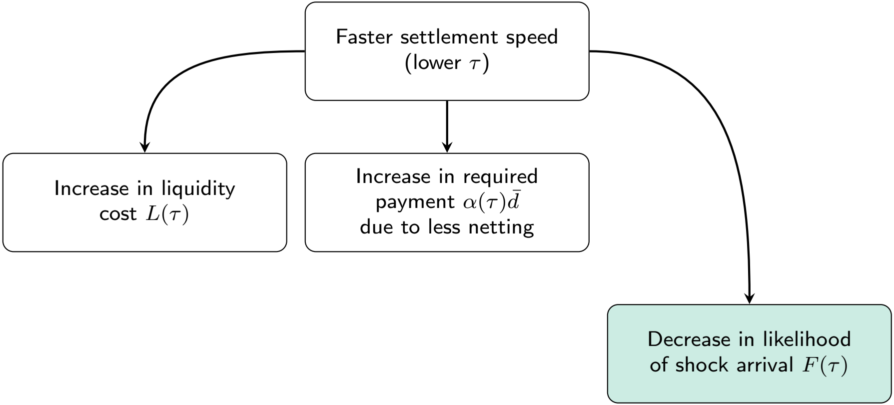

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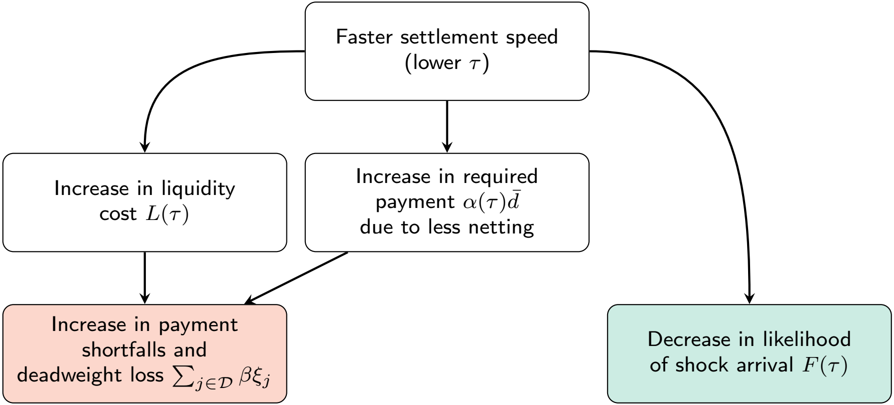

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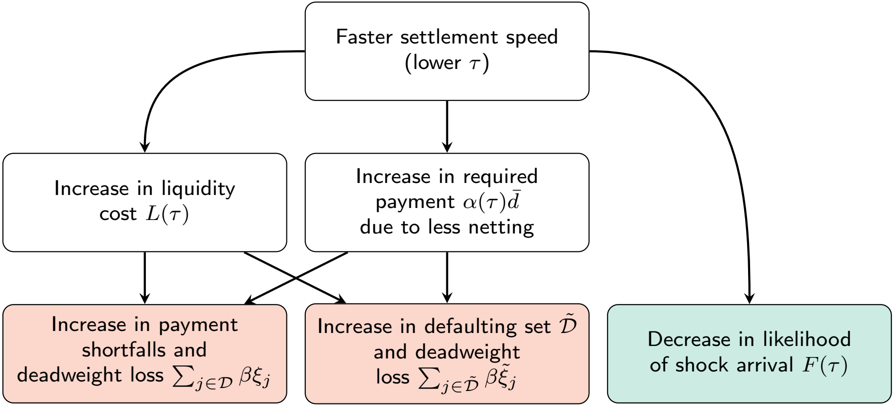

Identifying Default Thresholds (Proposition 4)

Proposition

Identification of default threshold points is solvable in polynomial time. Each node's default indicator is monotone in τ, so at most n thresholds per shock realization.

Implications:

- Computationally tractable
- Practical for evaluating settlement speed effects
- Can be implemented in policy analysis

Liquidity Conditions (Theorem 2)

If liquidity worsens ($L(\tau) \uparrow$ or $\bar{e} \downarrow$) from regime A (ample) to S (scarce):

1. **Threshold points shift:** $\tilde{\tau}_S > \tilde{\tau}_A$
2. **Higher welfare loss:** $W_S(\tau) > W_A(\tau)$
3. **Slower optimal speed:** $\tau_S^{opt} > \tau_A^{opt}$

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Key insight: Under scarce liquidity, financial stability favors (i) netting efficiency; and (ii) liquidity conservation, over rapid settlement, despite lower counterparty default probability

Policy Implications

1. **No one-size-fits-all:** Optimal settlement speed depends on:
   - Network structure
   - Liquidity conditions
   - Netting efficiency
2. **Targeted liquidity support** to central nodes during stress
3. **Paradox:** Faster settlement
   - $\downarrow$ Reduces crisis likelihood
   - $\uparrow$ Increases crisis severity $\Rightarrow$ more frequent interventions
4. **RTGS vs DNS choice** should consider liquidity conditions

Conclusion

Main contributions:

- First model to analyze settlement speed in payment networks with:
  - Time-varying netting and liquidity costs
  - Endogenous counterparty risk
- Key findings:
  - Discontinuous contagion patterns
  - Default threshold points critical for welfare
  - Network structure matters crucially
  - Liquidity conditions determine optimal speed
- Policy relevance:
  - Informs T+1 settlement debate
  - Guides payment system design
  - Justifies targeted liquidity facilities

Appendix

Agents and Payment Network

- Network of n agents in $N = \{1, 2, \ldots, n\}$
- Time is continuous $t \in [0, \bar{T}]$
- Cash buffer $e_i > 0$, Senior debt $s_i > 0$
- j's payment liability to i: d_{ij}
- Payment matrix $D \equiv [d_{ij}]_{i,j \in N}$
- j's total liability $d_j \equiv \sum_{i \in N} d_{ij}$
- Payment weight matrix $Q \equiv [q_{ij}]_{i,j \in N}$ with $q_{ij} = \dfrac{d_{ij}}{d_j}$

Settlement Speed, Netting, Liquidity

- Settlement time $\tau \in [0, \bar{T}]$

- Liquidity cost function $L(\tau)$ (decreasing in τ)

- Netting function $\alpha(\tau)$ (decreasing in τ, $\alpha(\tau) \in [0, 1]$)

- Partial netting matrix:

$$\hat{D} \equiv (1 - \alpha(\tau))\underline{D} + \alpha(\tau) D$$

where $\underline{D}$ is full netting matrix

Default Spillovers

- Payment by j: $x_j(\tau, D, \epsilon)$
- Pro rata distribution: payment to i from j is $q_{ij}x_j$
- Deadweight loss: $\min\{\beta\xi_j, A_j\}$ where

$$A_j = e_j + \sum_{k \in N} q_{jk} x_k$$
$$\xi_j = [\hat{d}_j + s_j + \epsilon_j + L(\tau) - A_j]^+$$

- $\beta > 0$: scaling parameter
- $\gamma \in [0, 1]$: feedback to network

Payment Equilibrium

- Total payments by j:

$$x_j = \begin{cases} \hat{d}_j, & \text{if } A_j \geq \hat{d}_j + L(\tau) + s_j + \epsilon_j \\ [A_j - L(\tau) - s_j - \epsilon_j - \min\{\beta\xi_j, A_j\}]^+, & \text{o.w.} \end{cases}$$

- Payment equilibrium vector x satisfies:

$$x = [\min\{\hat{d}, Qx + e - L(\tau)\mathbf{1} - s - \epsilon - \min\{\beta\xi, A\}\}]^+$$

- Focus on Pareto dominant equilibrium

Monotone Deadweight Loss (Lemma 1)

Lemma

Conditional on shock arrival, aggregate deadweight loss decreases as τ *increases. Furthermore,* $\mathcal{D}(\tau', \epsilon) \subseteq \mathcal{D}(\tau, \epsilon)$ *for* $\tau < \tau'$*.*

Intuition:

- $\alpha(\tau)$ and $L(\tau)$ decrease $\Rightarrow$ less liabilities and costs
- Decrease in liabilities exceeds decrease in payments from solvent counterparties
- Therefore payment shortfalls decrease

Node Depth Centrality

Aggregate deadweight loss with spectral radius $(1+\beta)Q_{\mathcal{D}} < 1$:

$$\beta \sum_{j \in \mathcal{D}} \xi_j \underbrace{\left(1 + (1+\beta) \sum_k q_{kj} + (1+\beta)^2 \sum_{k,l} q_{lk} q_{kj} + \cdots \right)}_{C_j(\mathcal{D}) = \text{Node depth centrality}}$$

Interpretation:

- Captures amplification through network
- Measures systemic importance
- Higher-order connections compound impact
- Key for computing total deadweight loss

Comparative Statics: Faster Settlement

Suppose τ decreases to τ':

Without change in default set:

- Increase in $L(\tau)$
- Decrease in inter-agent payments (amplifying effect)
- Increase in $\alpha(\tau)\bar{d}$ (less netting)

With change in default set:

1. More agents in $\sum_{j \in \mathcal{D}(\tau')}$
2. Centrality jumps: $C_j(\mathcal{D}(\tau)) \to C_j(\mathcal{D}(\tau'))$

But: Lower likelihood $F(\tau') < F(\tau)$

Empirical Implications

Testable hypotheses:

- Cross-market comparisons of systemic event likelihood/severity
- Network structure effects on contagion sensitivity
- Government intervention frequency in faster vs slower systems
- Liquidity conditions interaction with settlement speed
- Ex ante vs ex post stability measures
- RTGS vs DNS choice depending on liquidity (Copeland & Garratt, 2019)