Settlement Speed and Financial Stability

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Motivation

- Settlement is getting faster:
  - Securities: SEC T+1 settlement (effective May 28, 2024)
  - Payments: RTGS (Fedwire, T2, Lynx), instant payments (FedNow, RTP), faster deferred net settlement (CHIPS)
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  - Brazil's Pix instant payments: banks increased liquid asset holdings (Ding, Gonzalez, Ma, & Zeng, 2025)
  - Netting saves liquidity: CHIPS settles large gross obligations with small net cash outlays (Copeland & Garratt, 2019)
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- **Research Question:** Does faster settlement improve or worsen financial stability—and how does the answer depend on network structure and liquidity conditions?

Our Contribution

- Network model of payments with a **settlement time** τ:
  1. Networked payment flows
  2. Netting of obligations
  3. Liquidity costs of funding payments
  4. Liquidity shocks and counterparty defaults

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- Relative to McLaughlin (2023) and Khapko & Zoican (2020): specific network structures, default cascades, ex ante welfare

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Scope: systemic defaults (tail events), not routine settlement fails; D held fixed

Ex Ante Social Welfare Loss

- Ex ante welfare loss:

$$W(\tau, D) = \underbrace{nL(\tau)}_{\text{liquidity cost}} + \underbrace{F(\tau)}_{\text{shock prob}} \underbrace{E\Big[\sum_{j \in N} \min\{\beta\xi_j, A_j\}\Big]}_{\text{expected deadweight loss}}$$

- **Tradeoff:**
  - Faster ($\tau \downarrow$) $\Rightarrow$ higher $L(\tau)$, less netting, but lower $F(\tau)$
  - Slower ($\tau \uparrow$) $\Rightarrow$ lower $L(\tau)$, more netting, but higher $F(\tau)$

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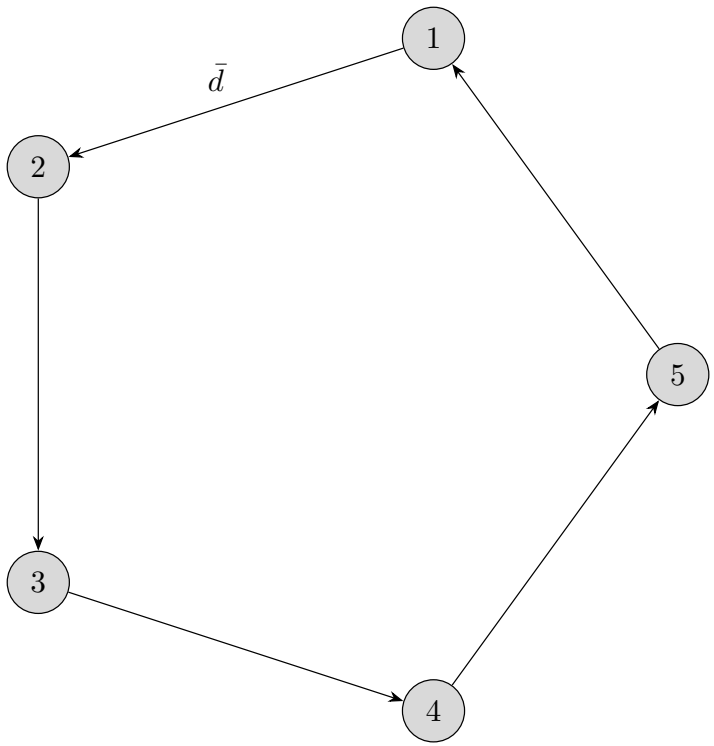
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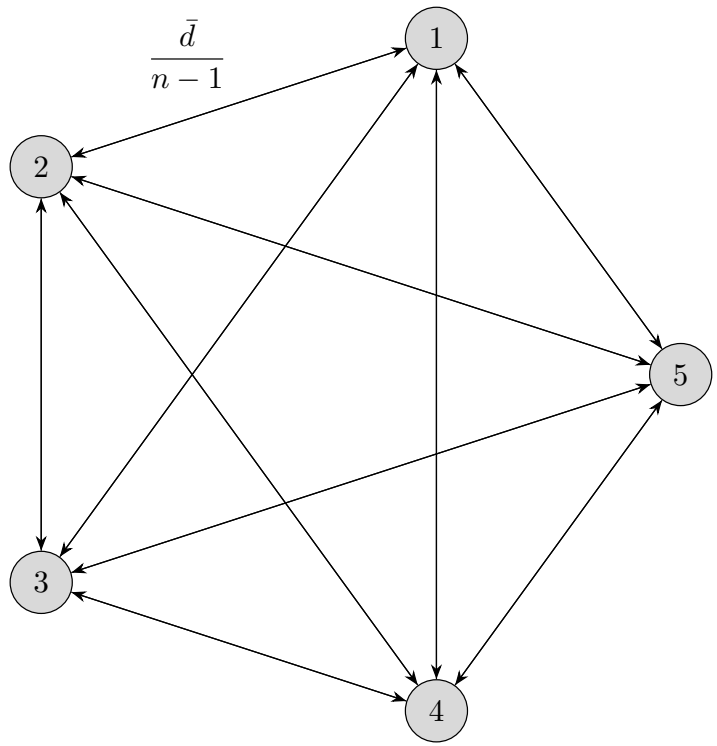
- **Ex post** (given a shock): deadweight loss & defaults $\downarrow$ as $\tau \uparrow$ (Lemma 1)
  $\Rightarrow$ faster settlement: lower likelihood, higher severity;
  ex ante effect is ambiguous

Ring vs Complete Network

Stylized setup: regular networks (homogeneous with in-/out-degree $\bar{d}$); one agent hit by a shock $\bar{\epsilon}$



D_r



D_c

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 a shock $\bar{\epsilon}$ hitting one agent**:

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Complete network:

- $\bar{\epsilon} \leq \epsilon^*(\tau)$ **or** $\alpha(\tau)\bar{d} \leq d^*(\tau)$: only the shocked agent defaults
- $\bar{\epsilon} > \epsilon^*(\tau)$ **and** $\alpha(\tau)\bar{d} > d^*(\tau)$: all agents default

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Ring network (same conditions):

- Either threshold not exceeded: the shocked agent plus ψ others default—the shortfall cascades along the ring
- Both exceeded: all default, with **higher total deadweight loss** than complete network (for small enough β)

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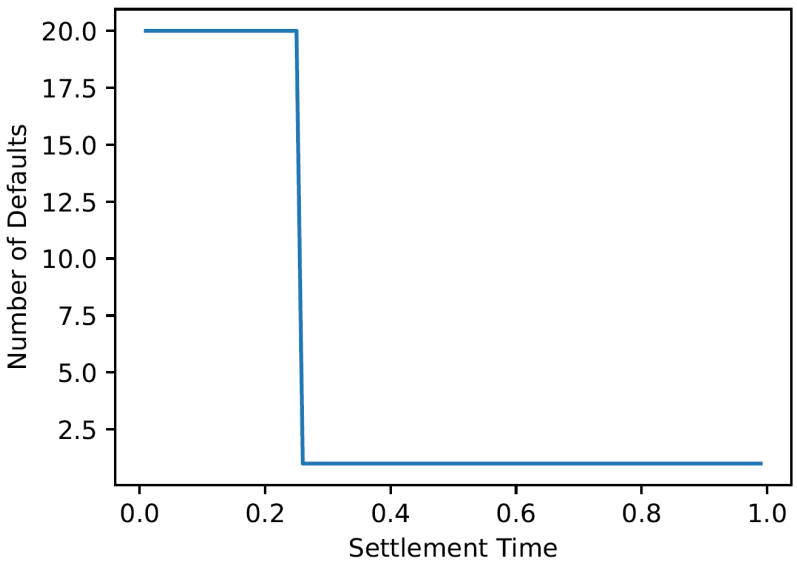
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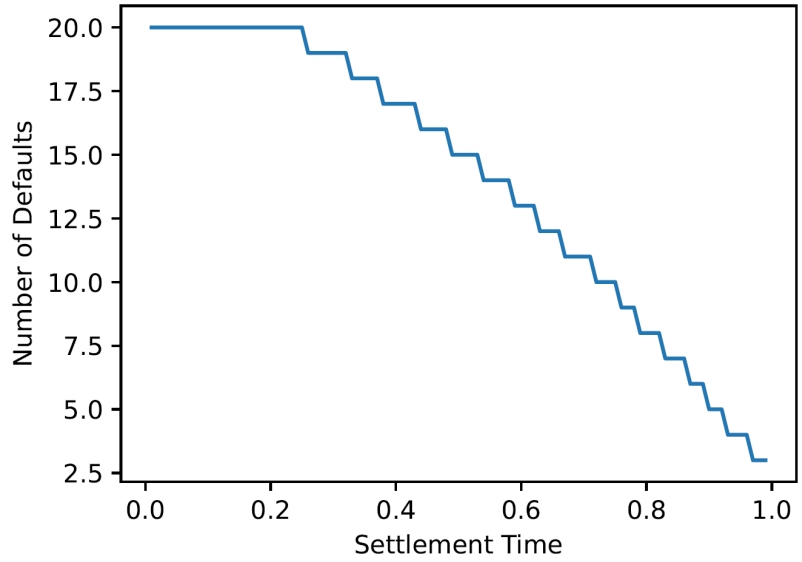
- Either threshold not exceeded: the shocked agent plus ψ others default—the shortfall cascades along the ring
- Both exceeded: all default, with **higher total deadweight loss** than complete network (for small enough β)

Unlike Acemoglu et al. (2015): same number of defaults $\neq$ same losses—payments recycled in the complete network reduce shortfalls

Ex Post Contagion: Complete vs. Ring



(a) Complete: phase transition at τ^*



(b) Ring: gradual change as τ falls

Number of defaults vs. τ, conditional on shock arrival

Corollary 1: all agents default in the complete network iff $\tau < \tau^*$

Ex Ante Welfare (Proposition 2)

1. **Slow settlement** ($\tau > \tau^*$): ranking of $\partial W/\partial \tau$ across the two networks is **ambiguous**

2. **Fast settlement** ($\tau \leq \tau^*$):

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

and possibly $$\frac{\partial W(\tau, D_c)}{\partial \tau} < 0 < \frac{\partial W(\tau, D_r)}{\partial \tau}$$

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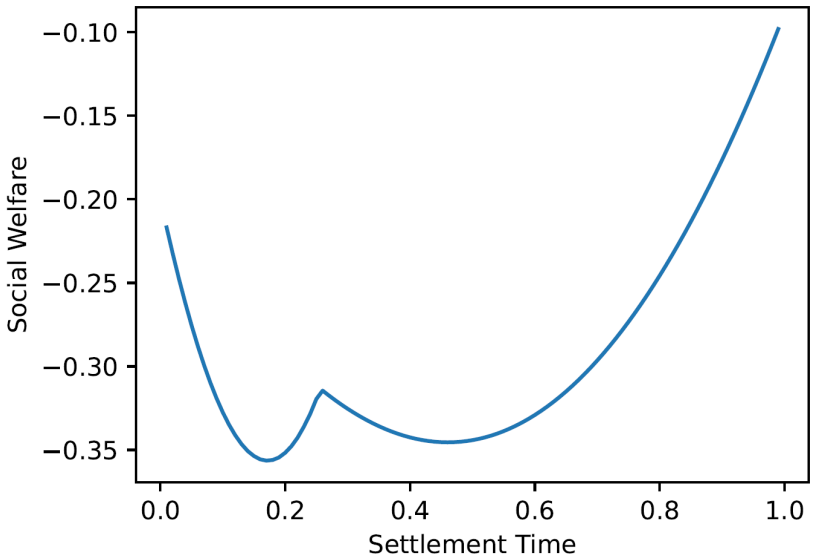
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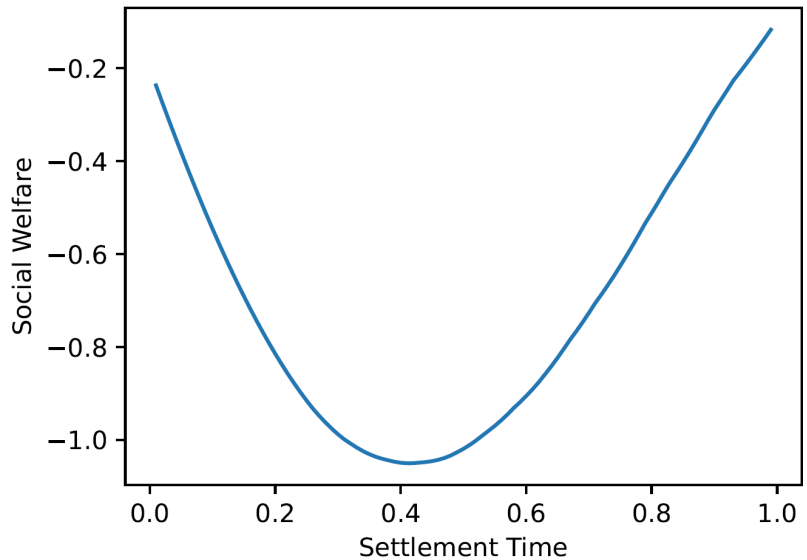
Implication: faster settlement can improve welfare in the ring network but worsen it in the complete network

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

Ex Ante Welfare Comparison



(a) Complete: kink at τ^*



(b) Ring: smooth changes

- Just below τ^*: slowing settlement raises welfare in the complete network but lowers it in the ring

- The global optimum depends on $\alpha(\cdot)$, $L(\cdot)$, $F(\cdot)$ and parameters

Welfare Decomposition (Proposition 3)

For a **general** regular network and a given shock state ϵ with an unchanged default set, the effect of a longer settlement lag ($\tau \uparrow$):

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

Default Threshold Points (Theorem 1)

Definition: $\tau \in \mathcal{T}(D)$ if a marginal decrease in τ enlarges the default set for some shock realization

Theorem 1: At a default threshold point,

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

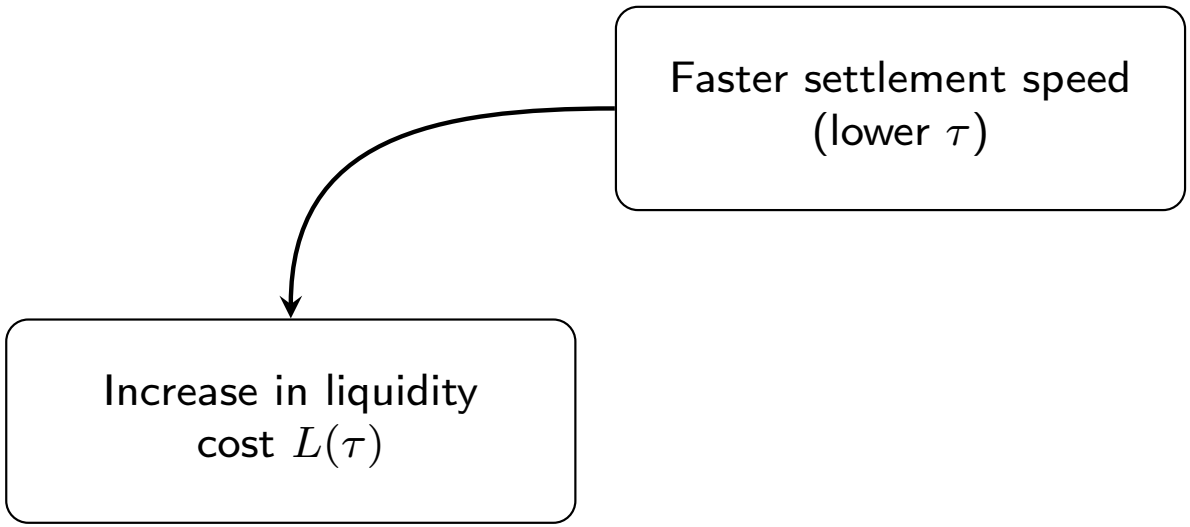
Implications:

- Welfare loss has a **kink**: its slope jumps at thresholds (extreme case: τ^* in the complete network)
- Away from thresholds, the sign of $\partial W/\partial \tau$ is ambiguous (netting, liquidity cost, F, centrality)
- Increasing τ can improve welfare exactly at a threshold
- Thresholds can be computed efficiently (Prop. 4)

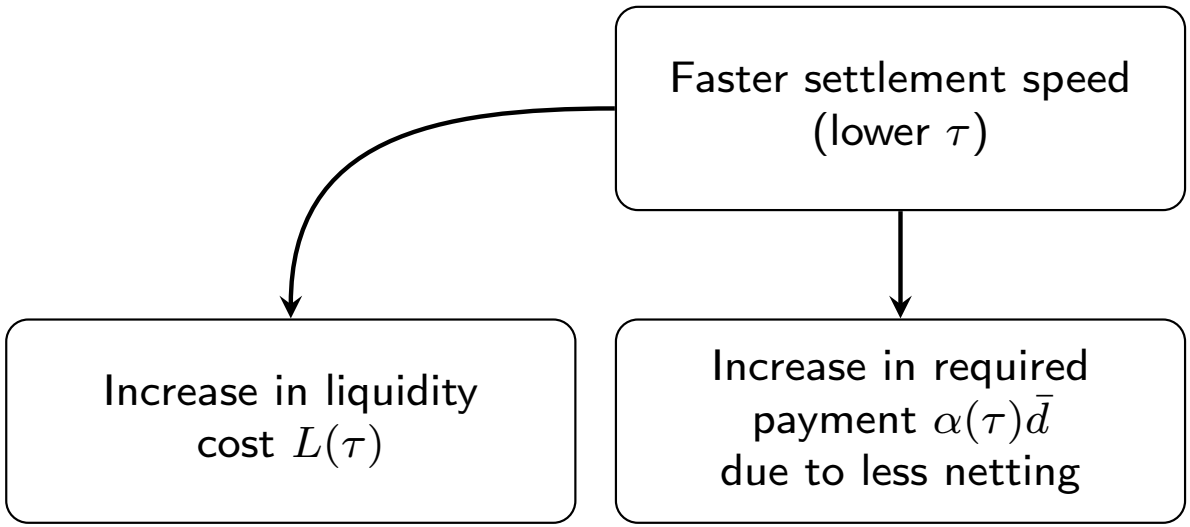
Impact of Faster Settlement Speed

Faster settlement speed
(lower τ)

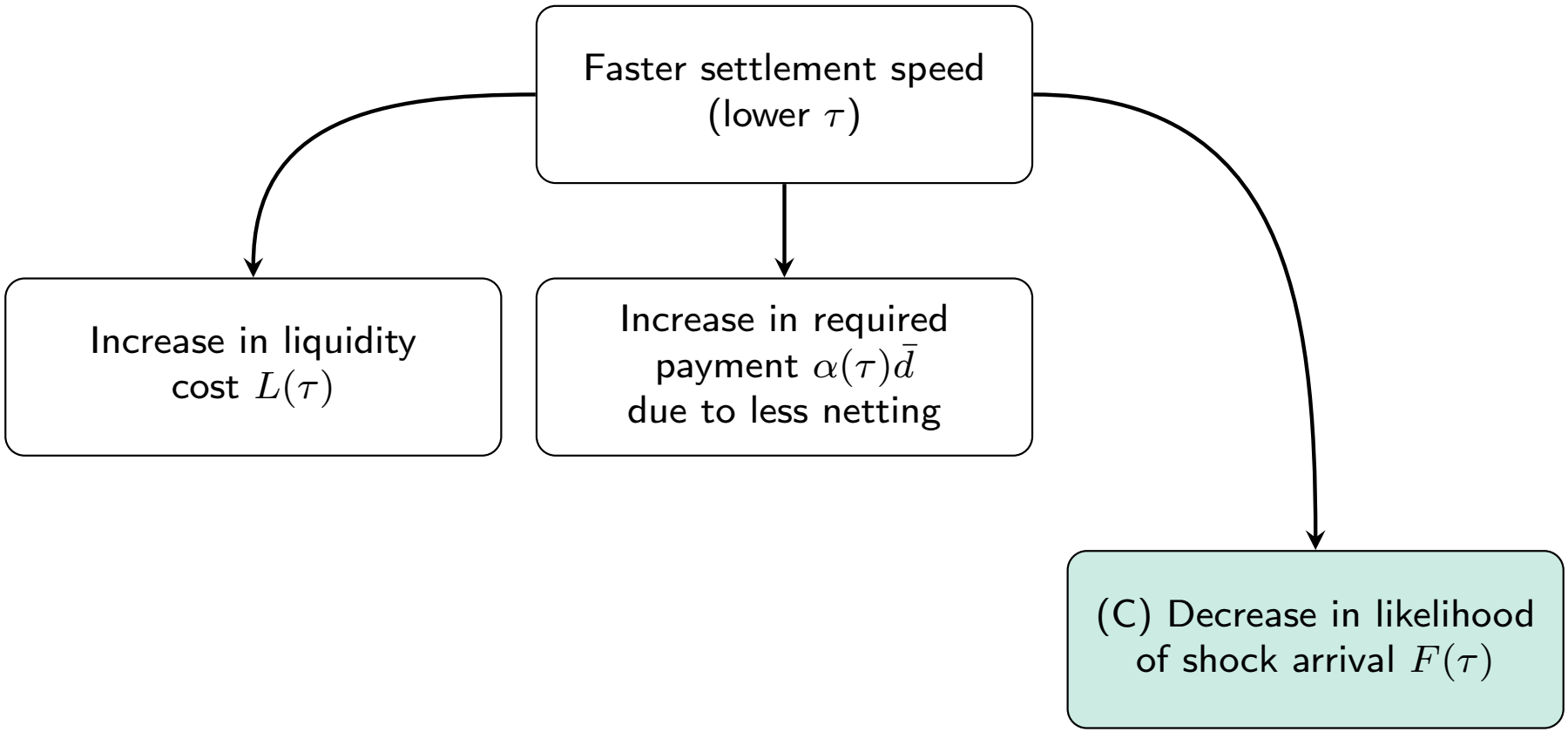
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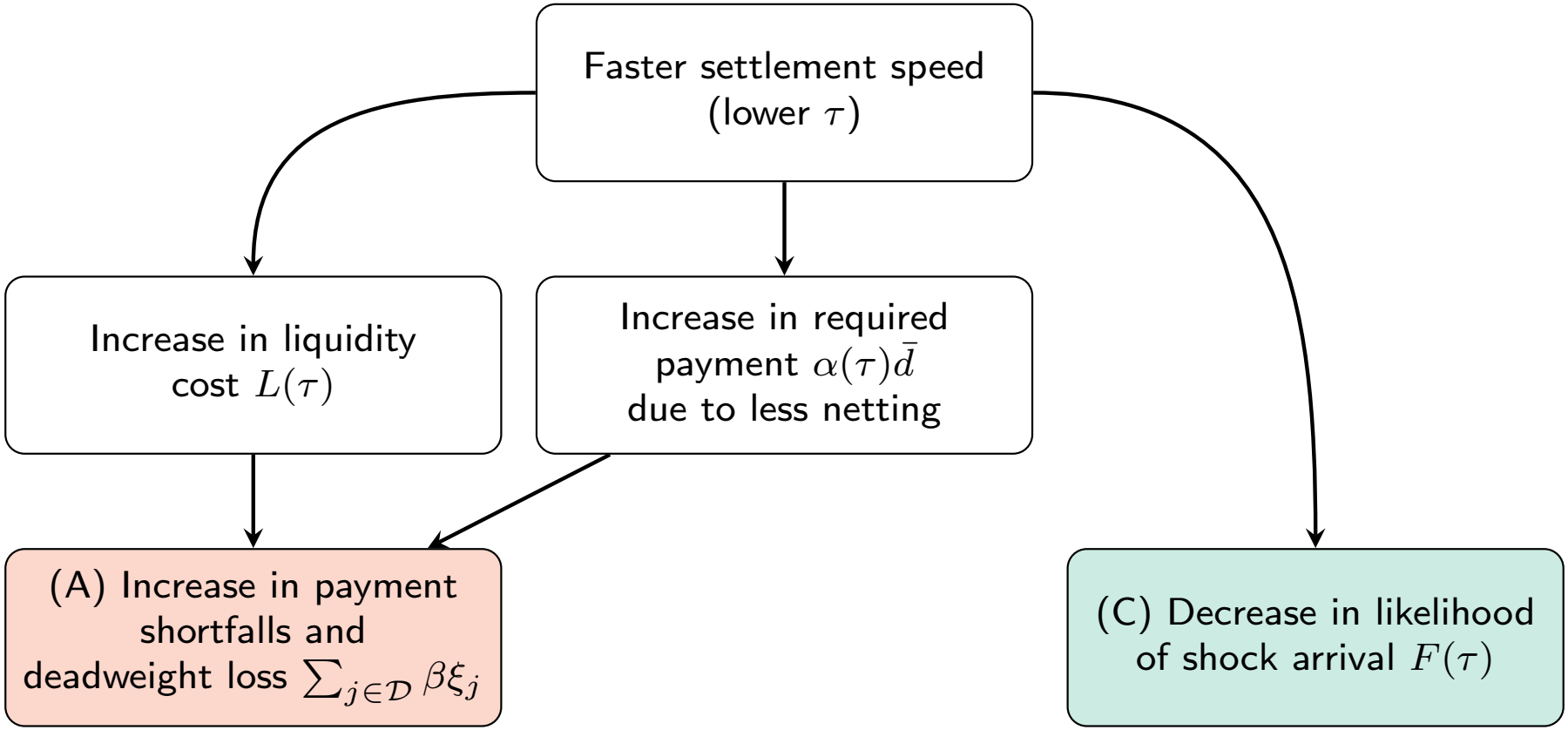
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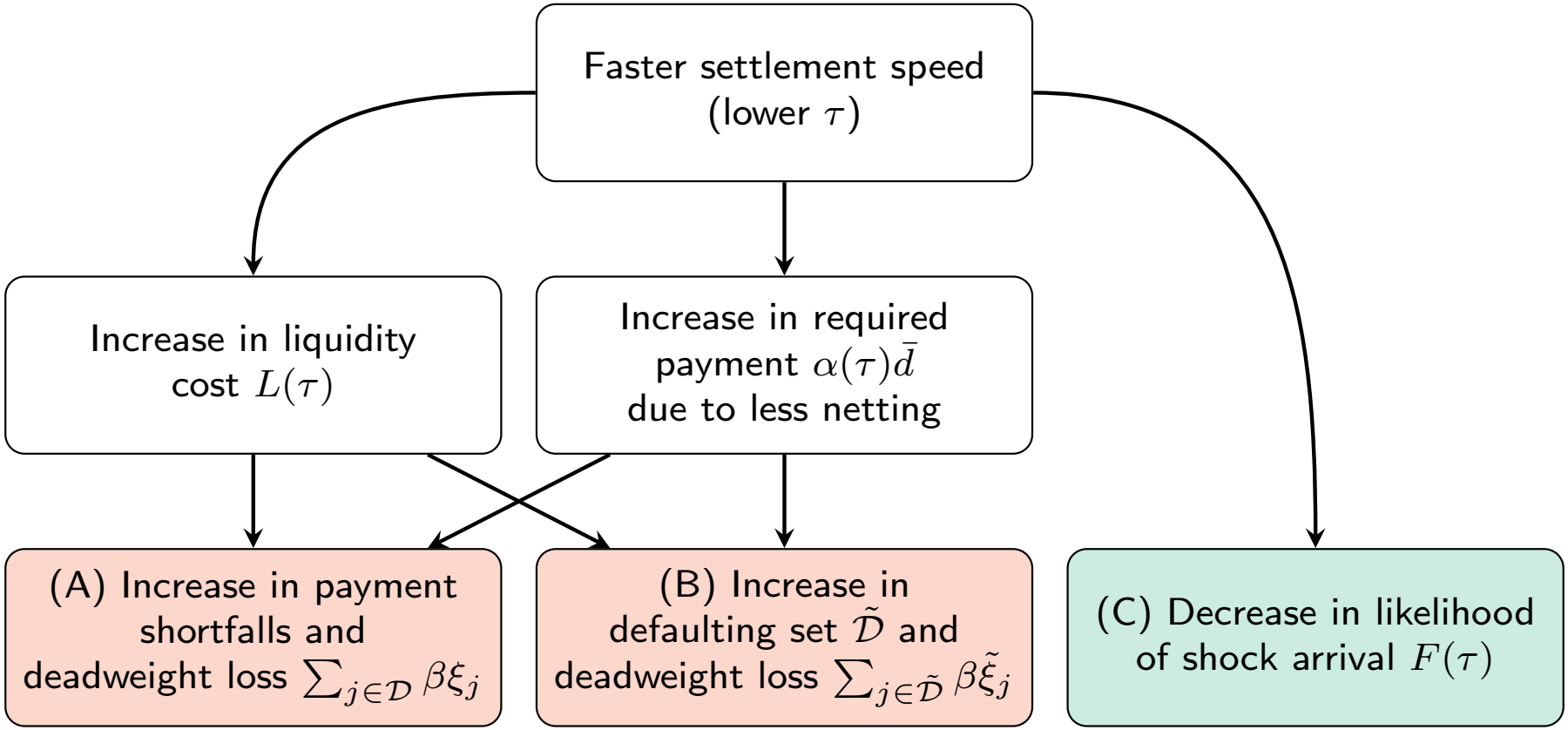
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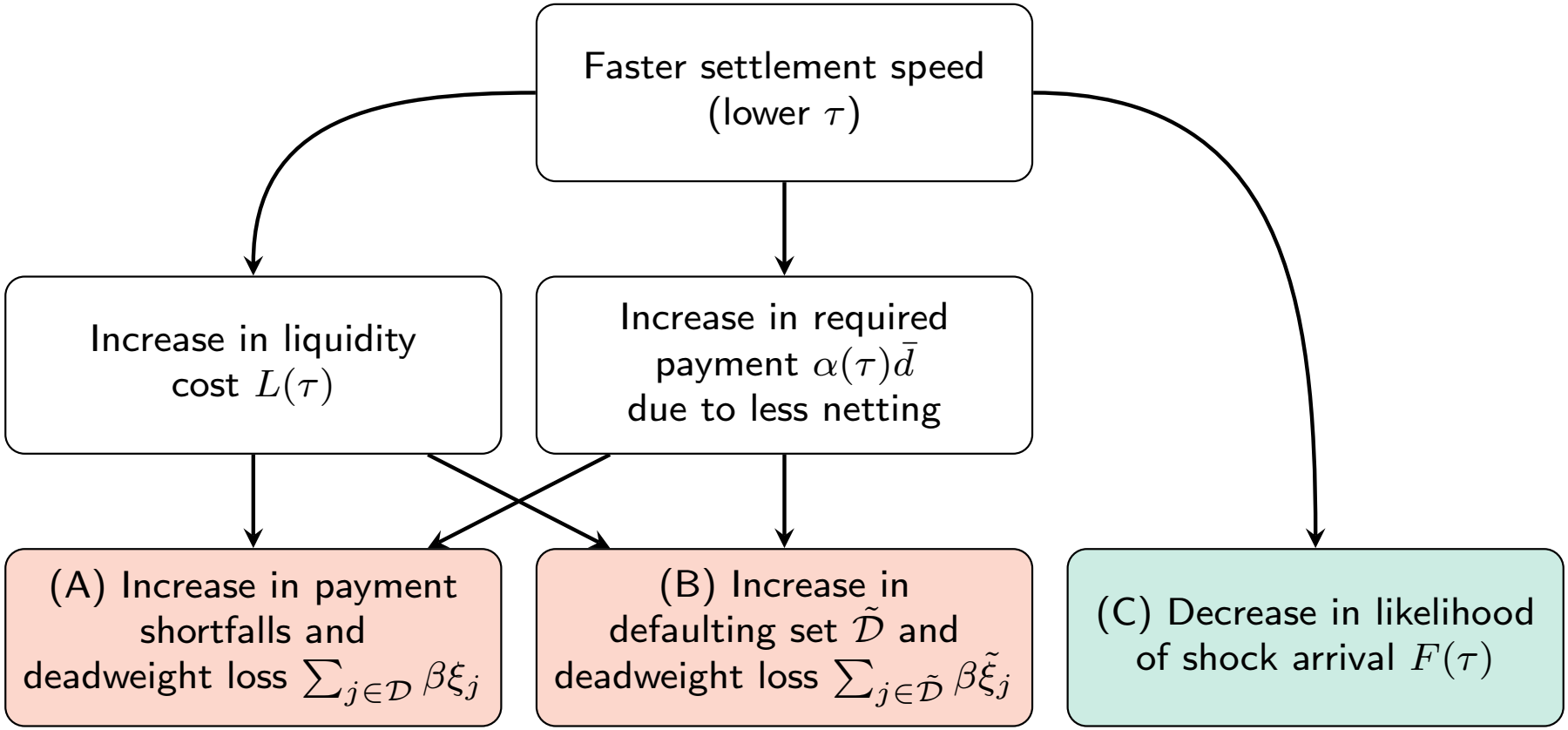
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Benefit (C) vs. **costs** (A) + (B); channel (B) operates only at default threshold points (Theorem 1)

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:** the same agent is on the verge of default at $\tilde{\tau}_S > \tilde{\tau}_A$

2. **Higher welfare loss:** $W_S(\tau, D) > W_A(\tau, D)$ for every τ

3. **Slower optimal speed:** $\tau_S^{opt} > \tau_A^{opt}$
   (if τ_S^{opt} is interior and locally unique, for a small deterioration in liquidity)

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Parts 1–2: theory behind reserves predicting liquidity crunches
(Copeland, Duffie, & Yang, 2025)
Part 3: rationalizes RTGS vs. DNS choice by liquidity conditions
(Copeland & Garratt, 2019)

Takeaways

1. **Faster is not always safer:** lower crisis likelihood, higher crisis severity $\Rightarrow$ potentially more frequent interventions

2. **No one-size-fits-all speed:** the optimum depends on network structure, netting, and liquidity; effects of marginal changes differ sharply at default threshold points

3. **Speed needs liquidity:** faster settlement combined with scarce liquidity can worsen stability $\Rightarrow$ intraday liquidity provision matters; liquidity conditions shape RTGS vs. DNS choice

4. **New technology** (e.g., DLT netting windows) shifts $\alpha(\tau)$ and $L(\tau)$, but the tradeoff remains

Related Literature 1/2

- Settlement speed tradeoff:
  McLaughlin (2023), Khapko and Zoican (2020)

- Financial networks (mostly ex post welfare):
  Allen and Gale (2000), 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); ex ante welfare: Chang and Chuan (2025)

- Netting and portfolio compression:
  Duffie and Zhu (2011), Carapella and Mills (2011), Duffie, Scheicher, and Vuillemey (2015), D'Errico and Roukny (2021), Chang (2021), Veraart (2022), Capponi, Wang, and Zhang (2022)

Related Literature 2/2

- Clearing and settlement design, liquidity provision:
  Williamson (1998, 2003), Fujiki, Green, and Yamazaki (2008), Koeppl, Monnet, and Temzelides (2008, 2012), Martin and McAndrews (2008)
- Payment systems and liquidity cost:
  VanHoose and Sellon Jr (1989), Rochet and Tirole (1996), Hancock and Wilcox (1996), McAndrews and Rajan (2000), Bech and Garratt (2003), Kahn, McAndrews, and Roberds (2003), Mills Jr and Nesmith (2008), Afonso and Shin (2011)
- RTGS vs DNS and liquidity conditions:
  Copeland and Garratt (2019), Ding, Gonzalez, Ma, and Zeng (2025), Copeland, Duffie, and Yang (2025)
- Liquidity under stress:
  Brunnermeier and Pedersen (2009), Acharya and Merrouche (2013), Andolfatto (2020)

Threshold Point (Corollary 1)

All agents default in complete network iff $\tau < \tau^*$, where $L(\tau^*) = L^*(\tau^*)$ and

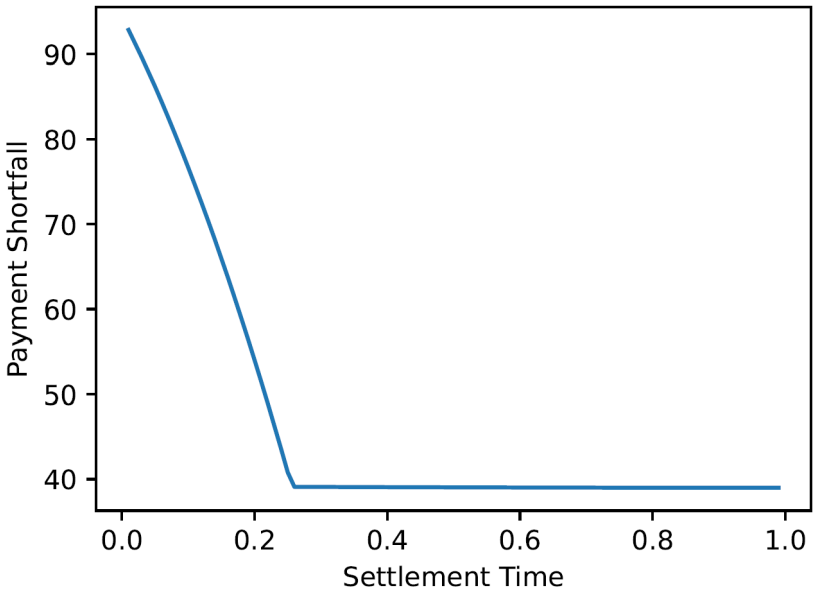
$$L^*(\tau) \equiv \bar{e} - \bar{s} - \min\left\{\frac{\bar{\epsilon}}{n}, \frac{\alpha(\tau)\bar{d}}{n-1}\right\}$$

Hence $\tau \leq \tau^*$ iff $L(\tau) \geq L^*(\tau)$ (the form used in Proposition 2)

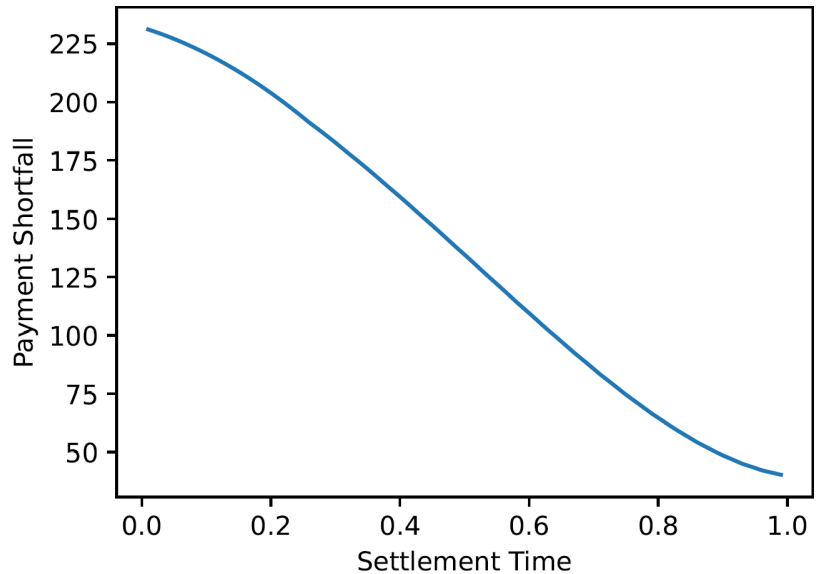
Implications:

- Threshold τ^* decreases in net cash buffer $\bar{e} - \bar{s}$
- Interaction between liquidity cost $L(\tau)$ and netting function $\alpha(\tau)$ determines the threshold
- Greater netting allows faster settlement without full contagion
- With little netting and large $\bar{d}$, the shock size $\bar{\epsilon}/n$ is the binding margin

Ex Post Payment Shortfall: Complete vs. Ring



(a) Complete: jump at τ^*



(b) Ring: smooth changes

Conditional on shock arrival. Under full contagion, the ring has the larger deadweight loss for small β: payments recycled in the complete network reduce shortfalls (Proposition 1)

Identifying Default Thresholds (Proposition 4)

Proposition

Identification of the set of default threshold points is solvable in polynomial time to any desired precision $\delta > 0$. Each node's default indicator is monotone in τ, so there are at most n thresholds per shock realization.

How:

- Payment equilibrium for a given τ: at most n iterations (Rogers and Veraart, 2013)
- Each switch point located by binary search: $O(\log((b-a)/\delta))$ solves per agent
- Continuous $G(\epsilon)$: finite discretization $\{\epsilon^{(1)}, \ldots, \epsilon^{(M)}\}$

Implication: computationally tractable for evaluating settlement speed changes in policy analysis

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 $L(\tau)$ (strictly decreasing in τ, senior to network payments)
- Netting function $\alpha(\tau) \in [0, 1]$: share of obligations not netted (decreasing in τ)
- Partial netting matrix:

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

where $\underline{D}$ is full netting matrix; weights $\hat{q}_{ij} = \hat{d}_{ij}/\hat{d}_j$

Default Spillovers

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

$$A_j = e_j + \sum_{k \in N} \hat{q}_{jk} x_k$$

$$\xi_j = [\hat{d}_j + s_j + \epsilon_j + L(\tau) - A_j]^+$$

- $\beta > 0$: scaling parameter
- $\gamma \in [0, 1]$: share of deadweight loss borne within the network ($\gamma = 0$ in stylized networks, $\gamma = 1$ in general networks)

Payment Equilibrium

- Total payments by j:

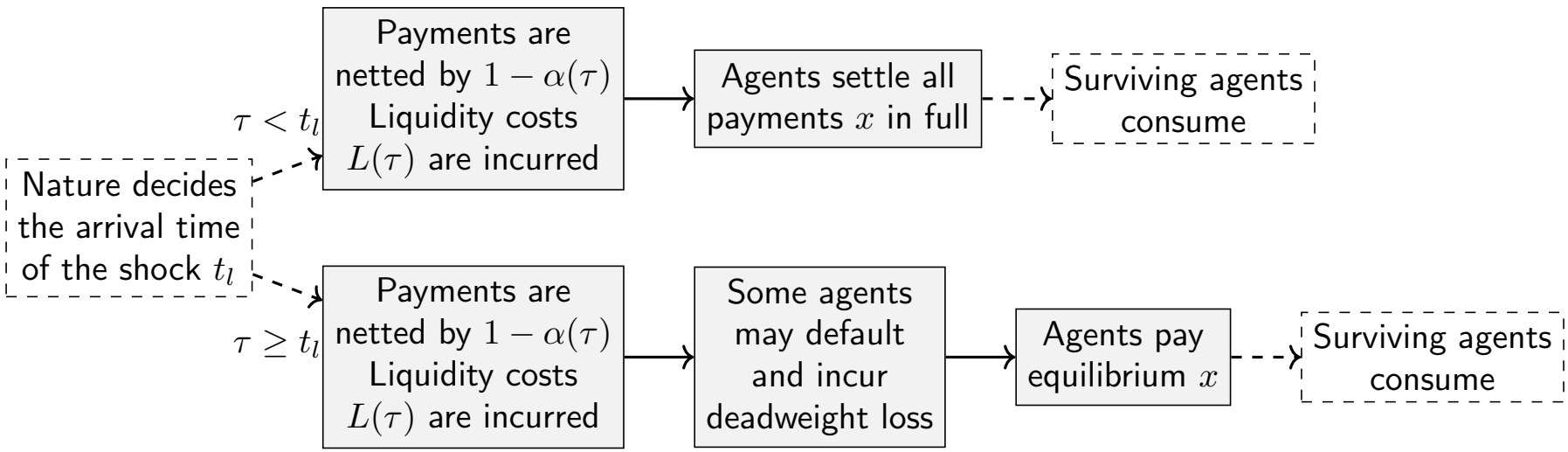
$$x_j = \begin{cases} \hat{d}_j, & \text{if } A_j \geq \hat{d}_j + L(\tau) + s_j + \epsilon_j \\ [A_j - L(\tau) - s_j - \epsilon_j - \gamma \min\{\beta \xi_j, A_j\}]^+, & \text{o.w.} \end{cases}$$

- Payment equilibrium vector x satisfies:

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

- Focus on Pareto dominant equilibrium

Timeline


Nature decides the arrival time of the shock t_l
$\tau < t_l$
Payments are netted by $1 - \alpha(\tau)$ Liquidity costs $L(\tau)$ are incurred
Agents settle all payments x in full
Surviving agents consume
$\tau \geq t_l$
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

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 when the spectral radius of $(1+\beta)Q_{\mathcal{D}}$ is below 1:

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

Interpretation:

- "Default contagion multiplier" (node depth centrality of Glasserman and Young, 2015)
- Measures systemic importance; jumps when the default set expands
- Basis for targeted liquidity support to central nodes
- Theorems 1–2 and Proposition 4 do not require the spectral radius condition

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:

- Likelihood vs. severity of systemic events across markets with different settlement speeds
- Network density and sensitivity of contagion to settlement speed
- Government intervention frequency in faster vs slower systems
- Liquidity conditions (reserve balances, funding costs) and liquidity crunches
- RTGS vs DNS choice depending on liquidity (Copeland & Garratt, 2019)
- Ex ante vs ex post stability measures
- Identification: staggered T+1 adoption across equity markets; differential RTGS adoption