BANK FOR INTERNATIONAL SETTLEMENTS

Distributed ledger technology and large value payments: a global game approach

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* The views expressed here are those of the authors and not necessarily those of the Bank for International Settlements.

Cross-border payments: how it works now

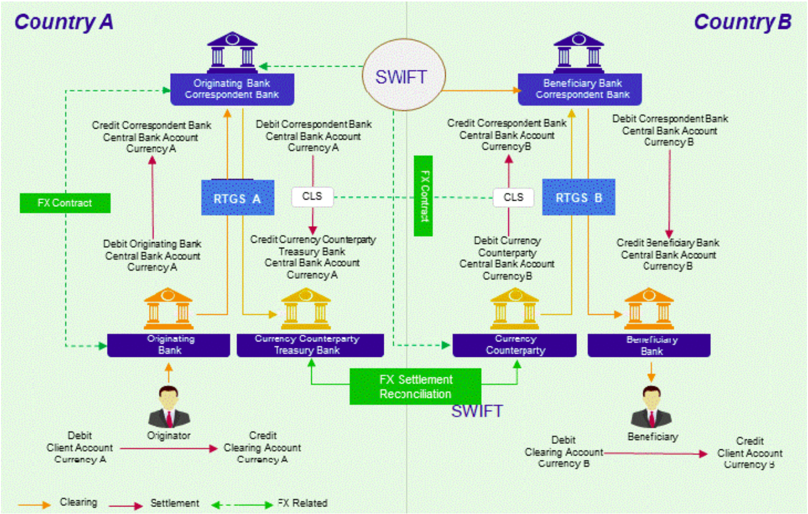


Figure: Payment through correspondent banks (source: "Cross-border interbank payments and settlements" Bank of Canada, Bank of England and Monetary Authority of Singapore, Nov 2018)

Distributed ledger technology (DLT) and the promise of decentralised consensus

Not only cryptocurrencies

Distributed ledger technology (DLT) in payment systems

- **Permissioned** versus permissionless blockchain
- **Private** versus public blockchain
- **Hierarchical** versus non-hierarchical blockchain

Validation of payments through decentralised consensus

- Agreement by supermajority (typically, 75-80 percent) is arbiter of truth

Where are we now?

Several central banks have experimented with DLT payment systems

- Cash-in-advance payment systems with digital tokens redeemable at central bank
  - Wholesale central bank digital currency (CBDC)
- Periodic netting arrangements to reduce credit needed for payments
- Central bank retains some role

Assessment so far

- Technology works, but advantages over existing payment systems yet to be demonstrated

Two issues

- How to ensure **confidentiality** of payments?
- How to overcome **need for credit** to finance payments?

Issue 1: how to ensure confidentiality?

Open, permissionless systems (eg, Bitcoin) have transactions visible to everyone, albeit with masked identities

Confidentiality of payments with oversight point to **private**, **hierarchical** DLT systems

- **Private**: banks and payment firms are voting nodes
- **Hierarchical**: central bank retains some role (eg, as notary)

Issue 2: how to provide credit to finance payments?

Real time gross settlement (RTGS) systems have heavy credit needs

- Daily payments $\approx$ 100 times the deposit balance held at central bank
- Banks rely on incoming payments to finance outgoing payments
- Bech and Garratt (JET 2003), Afonso and Shin (JMCB 2011)

Coordination problem arising from credit needs may swamp any technological refinements

Sources of funds in conventional domestic payment system

1. Balances maintained at the central bank
2. Borrowing from other banks through money markets
3. Credit extension from the central bank (eg, discount window or "daylight overdraft")
4. Incoming transfers from other banks

How to overcome **incentives to delay** when liquidity is scarce?

Who provides the credit to make the system work?

Payment flow disruptions on 9/11

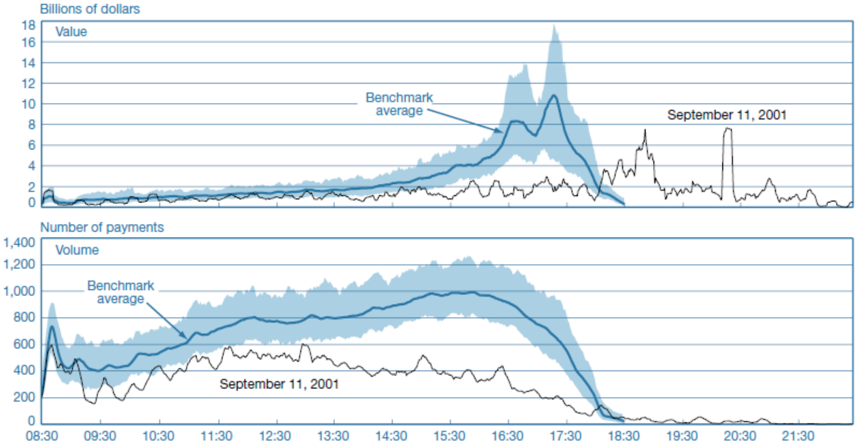


Figure: Payments on Fedwire per one minute interval (McAndrews and Potter, FRBNY Economic Policy Review, Nov 2002)

Responsiveness of outgoing payments as a function of incoming payments

McAndrews and Potter (FRBNY Economic Policy Review 2002)

- Payment reaction function:

$$P_t^A = a + bR_t^A + \text{controls} + \varepsilon_t$$

- P_t^A is payments made by bank A in one minute interval t
- R_t^A is payments received by bank A in 15 minute interval prior to t

Slope b is the payment reaction function
Estimated from panel of 20 large banks in Fedwire

Responsiveness of outgoing payments as a function of incoming payments

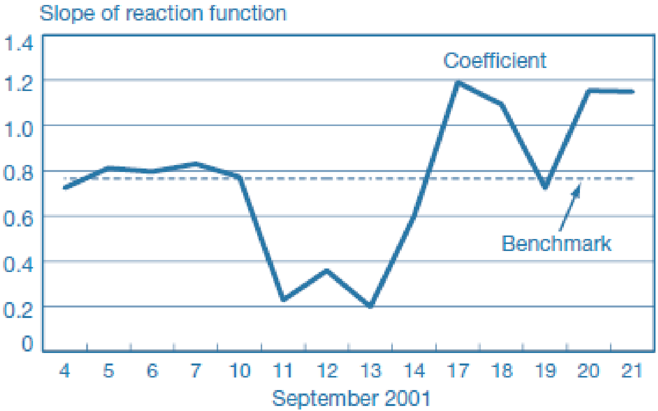


Figure: Slope of payment reaction function (McAndrews and Potter, FRBNY Economic Policy Review, Nov 2002)

Finding consensus in a decentralised system

- How to achieve consensus?
- How to achieve consensus *good enough for action* when there is something at stake?

- These are quite different questions, as **individual incentives** get in the way
  - Halpern and Moses (JACM 1990)
  - Rubinstein (AER 1989)
  - Morris, Rob and Shin (Econometrica 1995)

Two bank problem

Restatement of Halpern and Moses (1990)

- Two banks decide to **send** or **delay** a payment on behalf of respective clients
- Two states:
  - Good (G), with probability $1 - \delta$
  - Bad (B), with probability δ
- Bank 1 knows whether G or B is the case; Bank 2 does not
  - However, Banks 1 and 2 can send messages and confirmations to each other
  - Messages get through with probability $1 - \varepsilon$ (and $\delta > \varepsilon$)

Payoffs

- Payoffs in state G

	Send	Delay
Send	$1, 1$	$-M, 0$
Delay	$0, -M$	$0, 0$

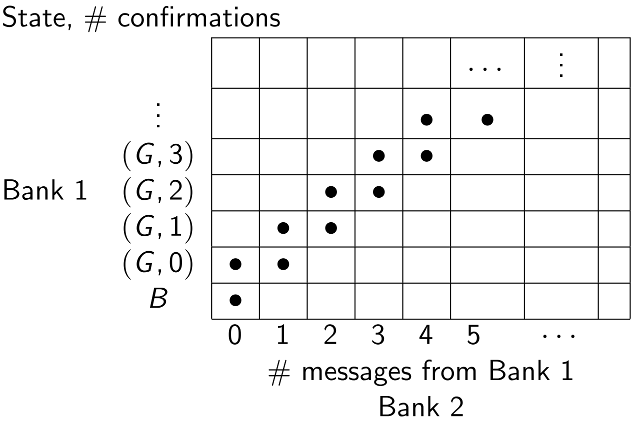
$M > 1$

- Payoffs in state B

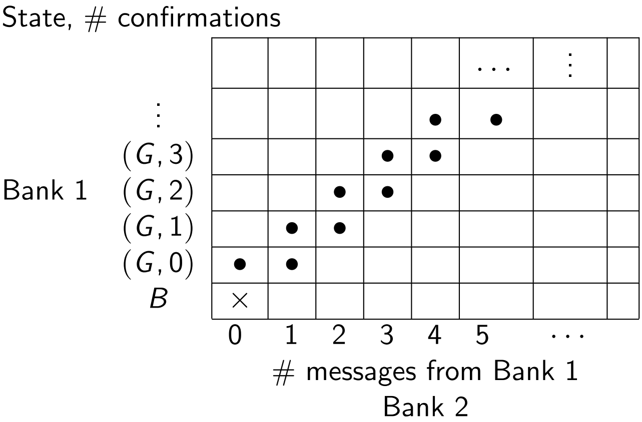
	Send	Delay
Send	$-M, -M$	$-M, 0$
Delay	$0, -M$	$0, 0$

- Sending in good state earns fee and good will of client $(+1)$ but incurs credit risk, unless other bank reciprocates
- Net payoff for bank when there is cost of credit: $-M$
- (Send in G, Delay in B) preferred by both banks

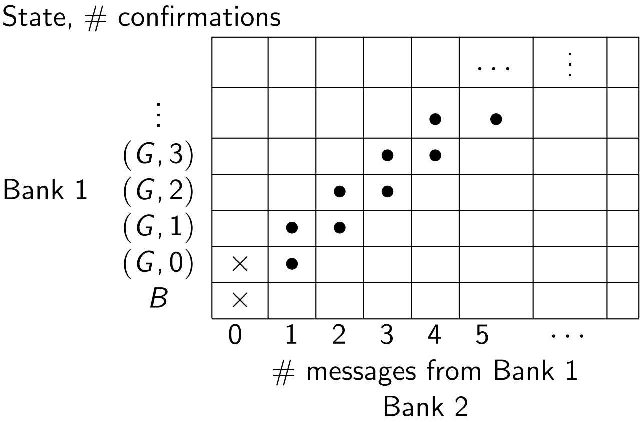
Strategy space



Bank 1 delays in bad state



Bank 2 delays when no message arrives



- Expected payoff to **pay** is $\frac{(1-\delta)\varepsilon-\delta M}{(1-\delta)\varepsilon+\delta} < 0$

Bank 1 delays when no confirmation arrives to message

State, # confirmations

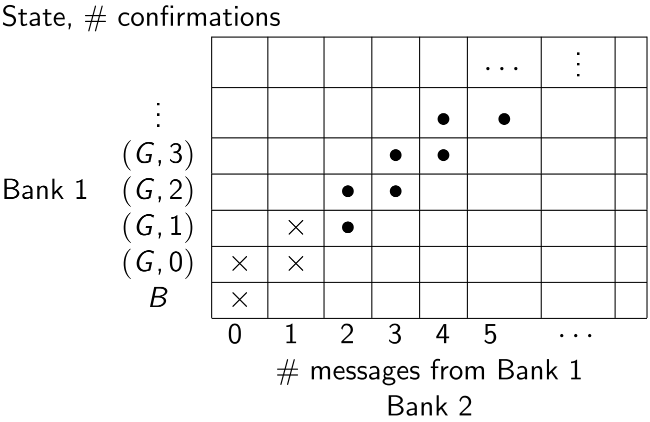
Bank 1		0	1	2	3	4	5	$\cdots$	
							$\cdots$	$\vdots$	
	$\vdots$					$\bullet$	$\bullet$		
	$(G,3)$				$\bullet$	$\bullet$			
	$(G,2)$			$\bullet$	$\bullet$				
	$(G,1)$		$\bullet$	$\bullet$					
	$(G,0)$	$\times$	$\times$						
	B	$\times$							

messages from Bank 1

Bank 2

- Either message did not get through ($\frac{(1-\delta)\varepsilon}{(1-\delta)\varepsilon+(1-\delta)\varepsilon(1-\varepsilon)}$) or confirmation did not get through, and the former is more likely
- Expected payoff to **pay** is $p \cdot 1 - (1-p)\, M < 0$, when $p < 0.5$ and $M > 1$

Bank 2 delays when no re-confirmation arrives



- Either confirmation did not get through or re-confirmation did not get through, and the former is more likely
- Expected payoff to **pay** is $p \cdot 1 - (1-p)\, M < 0$, since $p < 0.5$ and $M > 1$

Unique (dominance solvable) equilibrium is for both banks to delay irrespective of number of confirmations

State, # confirmations

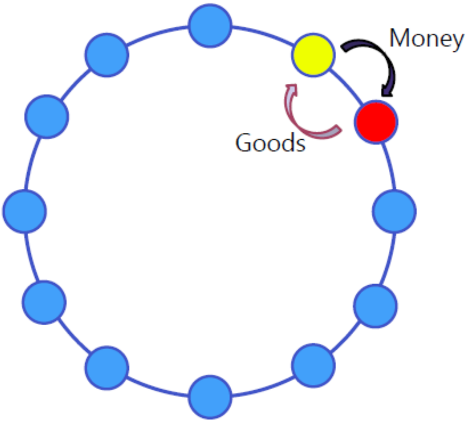
Bank 1									
							$\cdots$	$\vdots$	
	$\vdots$					$\times$	$\times$		
	$(G,3)$				$\times$	$\times$			
Bank 1	$(G,2)$			$\times$	$\times$				
	$(G,1)$		$\times$	$\times$					
	$(G,0)$	$\times$	$\times$						
	B	$\times$							
		0	1	2	3	4	5	$\cdots$	

messages from Bank 1

Bank 2

Stark difference between **consensus** and **consensus strong enough for action**

N bank problem



DLT payment system as a public good contribution game

Two aspects of public good

- Reconciled ledger of validated payments that commands consensus of nodes in the system
  - Agreement from enough nodes to exceed supermajority threshold
  - Typically 75-80 percent
- Sufficient credit provided by constituent nodes to achieve good outcome

First is amenable to technology; the second needs balance sheet backing

N bank problem

- N banks and N potential clients
- Each bank decides to **pay** or **delay**
  - Paying entails **granting credit line** to client at beginning of day
  - Cost to bank of granting credit line is $c > 0$
- Liquidity shocks are then realised
  - n clients need to draw on credit line to make payment
  - Surplus liquidity of the system is $N - n$
  - θ is latent variable for surplus liquidity, distributed uniformly on real interval
- Good outcome needs all N clients to make the payment
  - Good outcome yields payoff of $+1$ to bank

Public good contribution game

- N banks
- Bank i has signal $x_i = \theta + \varepsilon_i$, where ε_i is uniformly distributed noise over $[-\eta, +\eta]$
- Bank i decides to **grant liquidity line** or not based on x_i
- Supermajority voting threshold in DLT is $\hat{\kappa} \in (0, 1)$
- ℓ is number of banks that grant liquidity line
- Good outcome results when $\ell \geq n$ and $\ell \geq \hat{\kappa}$
- Threshold for ℓ to achieve good outcome:

$$\kappa = \max \{\hat{\kappa}, n\}$$

Payoff function

Payoff advantage of granting liquidity line over not doing so is

$$u(\kappa, \ell) = \begin{cases} 1 - c & \text{if } \ell \geq \kappa \\ \\ -c & \text{otherwise} \end{cases}$$

Interpretation as public good contribution game

- Cost of public good contribution is $c > 0$
- Benefit of public good is $+1$
- Public good is successfully provided if proportion κ or more of banks choose the “good” action

Solution

Lemma

Suppose all banks follow switching strategy

$$s\left(x_i\right) = \begin{cases} \textit{pay} & \textit{if } x_i \geq x^* \\ \\ \textit{delay} & \textit{if } x_i < x^* \end{cases}$$

where x^* is interior. Then, the density of ℓ conditional on $x_i = x^*$ is uniform over $\{0, 1, 2, \cdots, N\}$

Characterisation of solution

As density over ℓ is uniform, equilibrium switching point is smallest x^* for which $A \geq B$

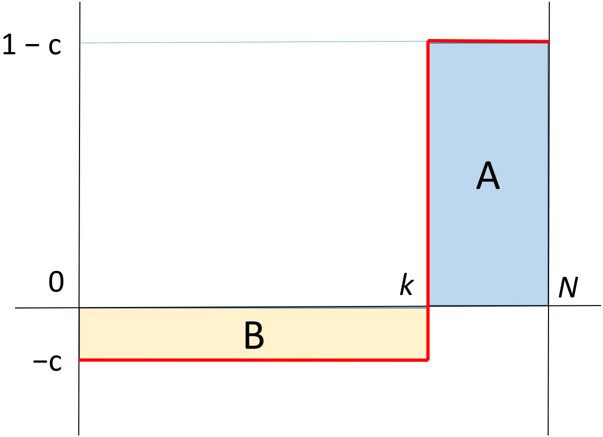
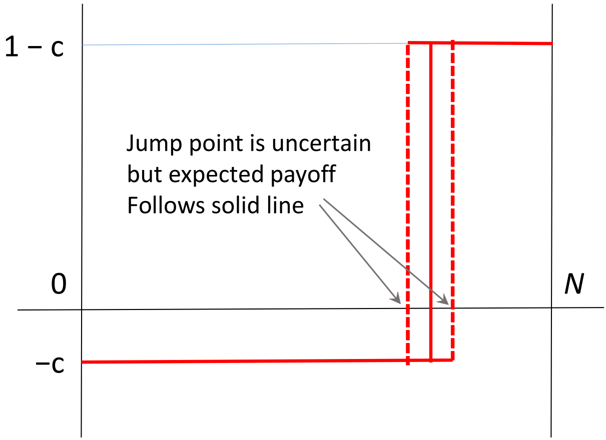


Figure: Expected payoff advantage to "pay"

Characterisation of solution

The jump point of the payoff difference is uncertain, but expected payoff difference is given by solid line



Characterisation of solution

Solution is highly sensitive to the cost of credit

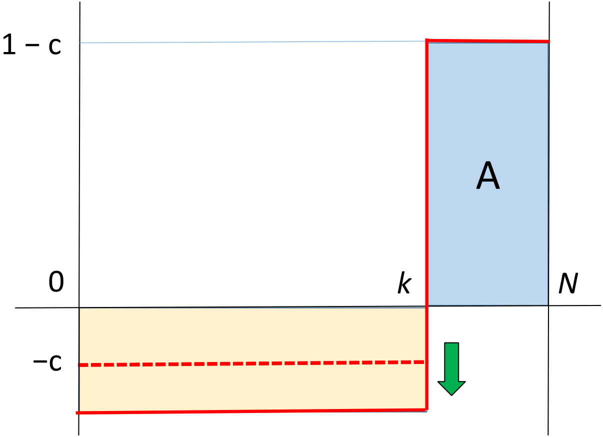


Figure: Solution is sensitive to the cost of credit

Characterisation of solution

Theorem

Good outcome is attainable in equilibrium if and only if

$$c \leq 1 - n/N \qquad \textit{and} \qquad c \leq \hat{k}$$

Characterisation of solution

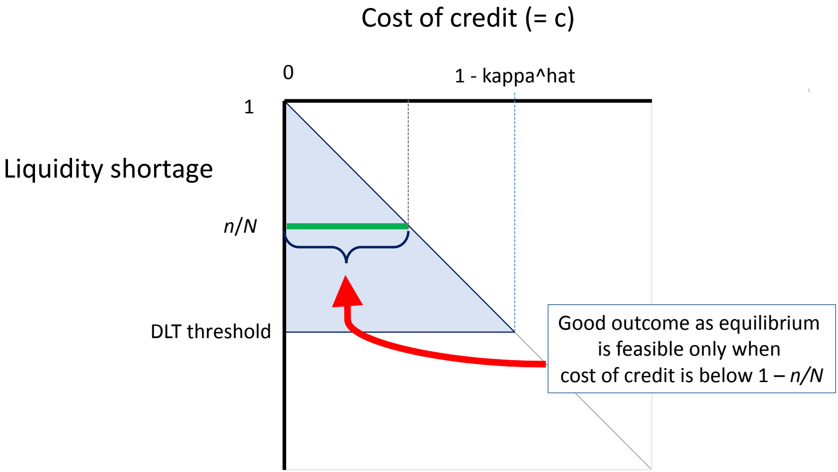


Figure: Coordination threshold is more stringent when liquidity need of the system is higher

Drawing lessons from the main theorem

- The cost of credit rules out good outcome in all but the most favourable states of the world, when constituents of payment system hold plentiful cash balances
- Cash-in-advance experiments with large central bank token balances are more likely to yield good outcomes
- More stringent test is when payment system participants have to rely on credit from outside to fund their payment activity

Conclusions

Two issues for DLT payment systems

1. How to overcome technological challenges in DLT for payment systems?
2. How to overcome **need for credit** to finance payments in large value payment systems?

- Early discussion and attention has been focused on (1).
- However, (2) is likely to prove more challenging for free-standing DLT systems that are less reliant on central bank balance sheets
- This is so especially in the **cross-border** and **cross-currency** context