The Demand for Programmable Payments

Charles M. Kahn[a] Maarten R.C. van Oordt[b,c]

[a]University of Illinois

[b]VU Amsterdam

[c]Tinbergen Institute

Virtual Seminar Series on
Central Banking & Digital Currencies

Friday, 28 April 2023

Why do we pay the way we do?

Why do we pay the way we do?

Why do we pay the way we do?

Programmable payments

"Programmable payment"

- "A transfer of funds that is automatically executed conditional upon preset objective criteria" (Bullock, 2018; Deutsche Bundesbank, 2020a; Arner et al., 2020; Bechtel et al., 2020)
- Can provide assurance by requiring the payer to precommit funds while delaying the release of funds to the payee until services or goods are delivered
- Could be enabled by, but does not necessarily require, "programmable money"
- Cryptocurrencies spurred innovation in this area (e.g., automation, no need for a custodian, cost reductions)

Programmable payments

“Programmable payment”

- “A transfer of funds that is automatically executed conditional upon preset objective criteria” (Bullock, 2018; Deutsche Bundesbank, 2020a; Arner et al., 2020; Bechtel et al., 2020)
- Can provide assurance by requiring the payer to precommit funds while delaying the release of funds to the payee until services or goods are delivered
- Could be enabled by, but does not necessarily require, “programmable money”
- Cryptocurrencies spurred innovation in this area (e.g., automation, no need for a custodian, cost reductions)

Programmable payments

"Programmable payment"

- "A transfer of funds that is automatically executed conditional upon preset objective criteria" (Bullock, 2018; Deutsche Bundesbank, 2020a; Arner et al., 2020; Bechtel et al., 2020)
- Can provide assurance by requiring the payer to precommit funds while delaying the release of funds to the payee until services or goods are delivered
- Could be enabled by, but does not necessarily require, "programmable money"
- Cryptocurrencies spurred innovation in this area (e.g., automation, no need for a custodian, cost reductions)

Programmable payments

Examples of advocated use cases:

- Automated escrow services
- Atomistic clearing and settlement for security transactions
- Forex transactions with digital currencies
- Enabling micropayments for pay-per-use concepts

Programmable payments

- A desirable feature for central bank digital currency?
  - Perhaps: Deutsche Bundesbank (2020b); Bank of England (2020); European Central Bank (2020); Wong and Maniff (2020); Usher et al. (2021); Eurogroup (2023)
- Launched as a payment solution for China's digital yuan

Programmable payments

- A desirable feature for central bank digital currency?
  - Perhaps: Deutsche Bundesbank (2020b); Bank of England (2020); European Central Bank (2020); Wong and Maniff (2020); Usher et al. (2021); Eurogroup (2023)
- Launched as a payment solution for China's digital yuan

Digital yuan solutions enjoy major upgrade

By ZHOU LANXU | China Daily | Updated: 2022-09-09 07:34

Programmable payments

Enthusiastic accounts often focus on technological ability, but ignore motivation for making payments

Technological developments raise interesting questions

- Could programmable payments become the new default mode of making payments?
- Will the number of payments explode as transactions costs drop? ("streaming money")

Programmable payments

Enthusiastic accounts often focus on technological ability, but ignore motivation for making payments

Technological developments raise interesting questions

- Could programmable payments become the new default mode of making payments?
- Will the number of payments explode as transactions costs drop? ("streaming money")

Programmable payments

Enthusiastic accounts often focus on technological ability, but ignore motivation for making payments

Technological developments raise interesting questions

- Could programmable payments become the new default mode of making payments?
- Will the number of payments explode as transactions costs drop? ("streaming money")

This Paper

- Analyze the desirability of programmable payments in a formal economic framework.
- Study optimal payment arrangement between buyer and seller
  - When does it require programmable payments?
- Stack the cards in favor of programmable payments:
  - High degree of automation so that the transaction cost of a programmable payment has fallen to a level comparable to that of a simple direct payment
  - No legal recourse in the event where either counterparty does not deliver upon their promises

This Paper

- Analyze the desirability of programmable payments in a formal economic framework.
- Study optimal payment arrangement between buyer and seller
  - When does it require programmable payments?
- Stack the cards in favor of programmable payments:
  - High degree of automation so that the transaction cost of a programmable payment has fallen to a level comparable to that of a simple direct payment
  - No legal recourse in the event where either counterparty does not deliver upon their promises

Preview of results

- Programmable payments are desirable in situations where economic relationships are of a short duration

- Optimal payment arrangements for long-term relationships consist predominantly of simple direct payments.
  - Value of long-term relationship sufficient to establish incentives for both counterparties to deliver on their promises
  - Simple direct payments avoid the liquidity cost of locking-up funds in programmable payments

- Different impact of lower transaction costs on number of payments across extensive and intensive margins

Relation to literature

Payments and smart contracts

- Bakos and Hałaburda (2019); Cong and He (2019); Gans (2019); Lee et al. (2021)

In contrast with others who study payments and smart contracts, we allow for endogenous timing of payments and repeated interactions

Model Environment

- Continuous time, risk neutral buyer and seller, common discount rate $\rho > 0$
- Seller can provide continuous flow of non-storable service at flow cost $c > 0$ per unit time
- Buyer flow utility from service is an exogenous function $b(t) \geq 0$ of time t
- Underlying payment system, with a transaction cost $K > 0$ imposed on the buyer for each payment made (captures transaction and administrative costs)

Model Environment

- Continuous time, risk neutral buyer and seller, common discount rate $\rho > 0$
- Seller can provide continuous flow of non-storable service at flow cost $c > 0$ per unit time
- Buyer flow utility from service is an exogenous function $b(t) \geq 0$ of time t
- Underlying payment system, with a transaction cost $K > 0$ imposed on the buyer for each payment made (captures transaction and administrative costs)

Model Environment

- No asymmetric information
- No government enforcement powers
- No intrinsic uncertainty

Single-Payment Arrangement

Consider a *single-payment* arrangement in an environment where $b(t)$ takes the form

$$b(t) = \begin{cases} b, & \text{if } t < T_M \\ 0, & \text{otherwise.} \end{cases}$$

Problem:
What is the optimal amount $D_1 \geq 0$ to pay at time $t = T_1$ and to, conditional upon receiving the service, release at $t = S_1$?

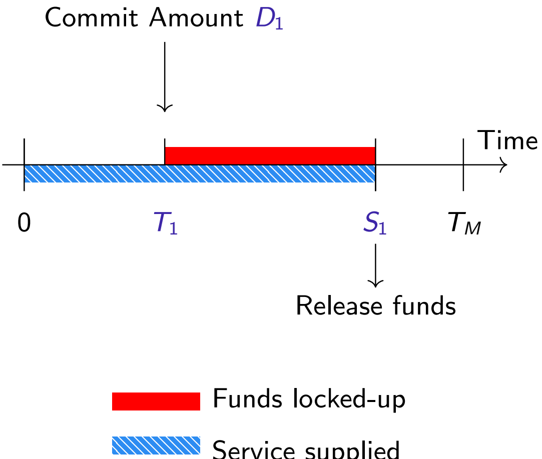
Single-Payment Arrangement

Consider a *single-payment* arrangement in an environment where $b(t)$ takes the form

$$b(t) = \begin{cases} b, & \text{if } t < T_M \\ 0, & \text{otherwise.} \end{cases}$$

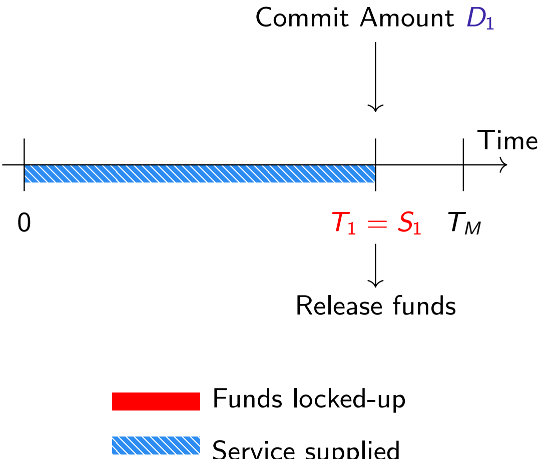
Problem:
What is the optimal amount $D_1 \geq 0$ to pay at time $t = T_1$ and to, conditional upon receiving the service, release at $t = S_1$?

Single-Payment Arrangement



$$T_1 \leq S_1 \leq T_M$$

Single-Payment Arrangement



Simple direct payment infeasible

Single-Payment Arrangement: Self-enforcement

A *self-enforcing* arrangement requires:

1) Seller willing to supply

$$D_1 e^{-\rho S_1} \geq c \int_0^{S_1} e^{-\rho t}\, dt$$

2) Buyer willing to pay when the time comes

$$b \int_{T_1}^{S_1} e^{-\rho t}\, dt \geq (D_1 + K) e^{-\rho T_1}$$

Single-Payment Arrangement: Self-enforcement

A *self-enforcing* arrangement requires:

1) Seller willing to supply

$$D_1 e^{-\rho S_1} \geq c \int_0^{S_1} e^{-\rho t}\, dt$$

2) Buyer willing to pay when the time comes

$$b \int_{T_1}^{S_1} e^{-\rho t}\, dt \geq (D_1 + K) e^{-\rho T_1}$$

Single-Payment Arrangement: Feasibility

Trading is *feasible* if a self-enforcing arrangement exists

Theorem

Assume T_M is large. Trading is feasible if and only if

$$\sqrt{b} \geq \sqrt{c} + \sqrt{\rho K}$$

We will refer to this condition as the *feasibility condition*

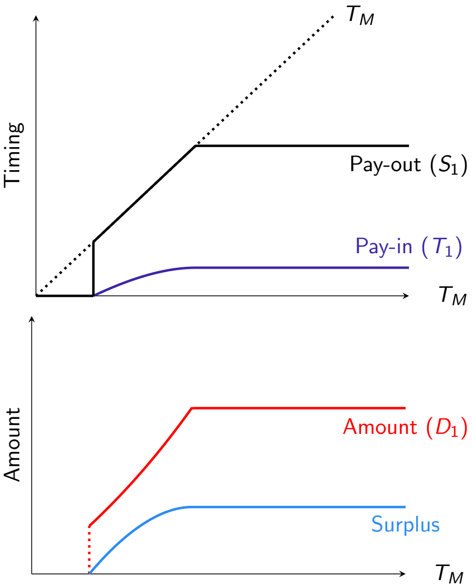
Single-Payment Arrangement: Optimal arrangement

The buyer solves the following problem:

$$\max_{D_1, T_1, S_1} b \int_0^{S_1} e^{-\rho t} \, dt - (D_1 + K) e^{-\rho T_1}$$

subject to the constraints for a self-enforcing arrangement.

Single-Payment Arrangement: Solution

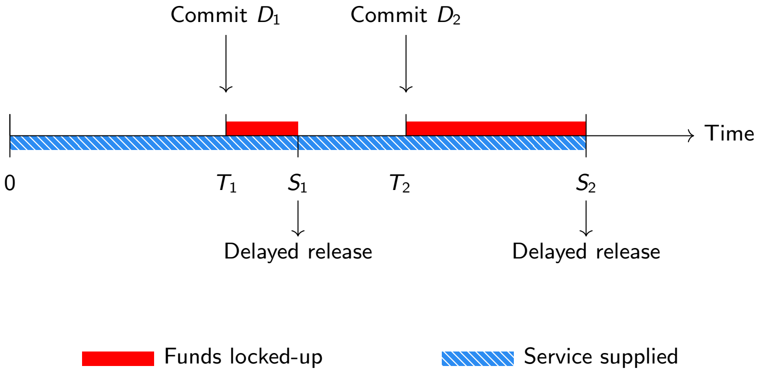


Chains of Payments

- Limited duration of single-payment relationship
- What do optimal chains of multiple payments look like?
- Look at two-payment arrangement to understand general point for multi-payment arrangements

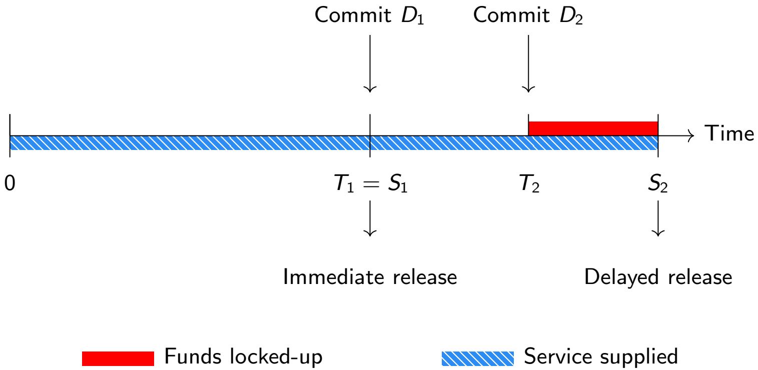
Optimal two-payment arrangement: Case 1

Both payments programmable



Optimal two-payment arrangement: Case 2

First payment direct, second payment programmable



Multi-payment arrangements

The value of a future relationship creates "trust"

Let the trust-variable W denote the present value of the remainder of the relationship to the buyer immediately after a payment is released to the seller.

Theorem

Assume the feasibility-condition holds true. If $W \geq (b - c - \rho K)/(2\rho)$, then any earlier payments – including the last payment – are direct payments.

Multi-payment arrangements

The value of a future relationship creates "trust"

Let the trust-variable W denote the present value of the remainder of the relationship to the buyer immediately after a payment is released to the seller.

Theorem

Assume the feasibility-condition holds true. If $W \geq (b - c - \rho K)/(2\rho)$, then any earlier payments – including the last payment – are direct payments.

Multi-payment arrangements

Endogenous number of payments

Theorem

Assume the feasibility-condition holds true. Every optimal chain of payments will start with direct payments as long as the horizon T_M is sufficiently remote.

Stationary Environment: Optimal solutions

Theorem

If the feasibility-condition holds true and $b(t) = b$ for all t, then the optimum is reached by a payment arrangement consisting of direct payments only.

Transaction Costs and the Frequency of Payments

Extensive margin (+):

Corollary

Lowering the transaction cost relaxes the feasibility-condition

$$\sqrt{b} \geq \sqrt{c} + \sqrt{\rho K}.$$

Intensive margin (−):

Corollary

Within a stationary environment, the size of each payment increases and the frequency of payments decreases as the transaction cost decreases.

Thus reducing transaction cost has an ambiguous effect on the number of payments made in an economy.

Transaction Costs and the Frequency of Payments

Extensive margin (+):

Corollary

Lowering the transaction cost relaxes the feasibility-condition

$$\sqrt{b} \geq \sqrt{c} + \sqrt{\rho K}.$$

Intensive margin (−):

Corollary

Within a stationary environment, the size of each payment increases and the frequency of payments decreases as the transaction cost decreases.

Thus reducing transaction cost has an ambiguous effect on the number of payments made in an economy.

Transaction Costs and the Frequency of Payments

Extensive margin (+):

Corollary

Lowering the transaction cost relaxes the feasibility-condition

$$\sqrt{b} \geq \sqrt{c} + \sqrt{\rho K}.$$

Intensive margin (−):

Corollary

Within a stationary environment, the size of each payment increases and the frequency of payments decreases as the transaction cost decreases.

Thus reducing transaction cost has an ambiguous effect on the number of payments made in an economy.

Concluding remarks

Starting point
What the payment is accomplishing is central to understanding the potential demand for a new payment mechanism

Results
Programmable payments come into play when the need is large but temporary

Repeated interaction and prospect for future gains enforce service provision and debt repayment

This trust mechanism reduces the need for programmable payments

Concluding remarks

Analysis emphasized an extreme case without external sources of trust (no residual continuation value).

Not essential for our results. Factors contributing to trust

- Legal recourse
- Settlement techniques and card networks (convert small relationships into larger levels of trust)
- Reputation mechanisms

Extended results (in appendix) show that residual continuation value further reduces the need for programmable payments.

Thank you!

Paper link:

References

D. Arner, R. Auer, and J. Frost. Stablecoins: Risks, Potential and Regulation. BIS Working Paper, 905, 2020.

Y. Bakos and H. Hałaburda. Smart Contracts, IoT Sensors and Efficiency: Automated Execution vs. Better Information. Working Paper, 2019.

Bank of England. Central Bank Digital Currency: Opportunities, Challenges and Design. Discussion Paper, 2020.

A. Bechtel, J. Gross, P. Sandner, and V. von Wachter. Programmable Money and Programmable Payments. Blog post (September 29), 2020. URL https://tinyurl.com/36rfyd5x.

M. Bullock. Financial Technology and Payments Regulation. Keynote Speech at the 5th Bund Summit on Fintech (July 8), 2018. URL https://www.bis.org/review/r180723g.pdf.

L.W. Cong and Z. He. Blockchain Disruption and Smart Contracts. Review of Financial Studies, 32(5):1754–1797, 2019.

Deutsche Bundesbank. Money in Programmable Applications: Cross-sector Perspectives from the German Economy. Technical Report, 2020a. URL https://tinyurl.com/mr2vvuws.

Deutsche Bundesbank. Rising Demand for Programmable Payments. Press Release (21 December), 2020b. URL https://tinyurl.com/3xbjayyh.

Eurogroup. Eurogroup Statement on the Digital Euro Project. Press Release (16 January), 2023. URL https://tinyurl.com/28d2axea.

European Central Bank. Report on a Digital Euro. Report, 2020.

J.S. Gans. The Fine Print in Smart Contracts. NBER Working Paper, 25,443, 2019.

T. Koeppl, C. Monnet, and T. Temzelides. Optimal Clearing Arrangements for Financial Trades. Journal of Financial Economics, 103(1):189–203, 2012.

M. Lee, A. Martin, and R.M. Townsend. Optimal Design of Tokenized Markets. Working Paper, 2021.

A. Usher, E. Reshidi, F. Rivadeneyra, and S. Hendry. The Positive Case for a CBDC. Bank of Canada Staff Analytical Note, 2021-11, 2021.

P. Wong and J.L. Maniff. Comparing Means of Payment: What Role for a Central Bank Digital Currency? FEDS Notes (August 13), 2020. URL https://tinyurl.com/2p986z2h.

Lessons for traditional payment systems

- Bill payments
  - Micro-foundations for bill payments
  - Trust from repeated interactions

- Payment systems as middle-men
  - Routing payments through middle-men creates repeated interactions (and, hence, trust)
    - Example: credit cards
    - Analogy with clearing house benefits in Koeppl et al. (2012)
  - Consolidation of payments makes trading feasible in situations where transaction costs (e.g., wire transfers) are otherwise prohibitively high

$$\sqrt{nb} \geq \sqrt{nc} + \sqrt{\rho K}$$

Lessons for traditional payment systems

- Bill payments
  - Micro-foundations for bill payments
  - Trust from repeated interactions

- Payment systems as middle-men
  - Routing payments through middle-men creates repeated interactions (and, hence, trust)
    - Example: credit cards
    - Analogy with clearing house benefits in Koeppl et al. (2012)
  - Consolidation of payments makes trading feasible in situations where transaction costs (e.g., wire transfers) are otherwise prohibitively high

$$\sqrt{nb} \geq \sqrt{nc} + \sqrt{\rho K}$$

Lessons for traditional payment systems

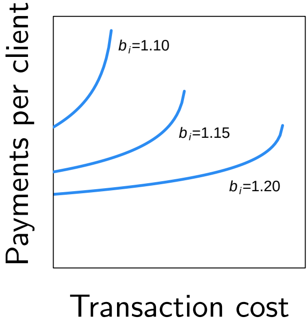
- Bill payments
  - Micro-foundations for bill payments
  - Trust from repeated interactions

- Payment systems as middle-men
  - Routing payments through middle-men creates repeated interactions (and, hence, trust)
    - Example: credit cards
    - Analogy with clearing house benefits in Koeppl et al. (2012)
  - Consolidation of payments makes trading feasible in situations where transaction costs (e.g., wire transfers) are otherwise prohibitively high

$$\sqrt{nb} \geq \sqrt{nc} + \sqrt{\rho K}$$

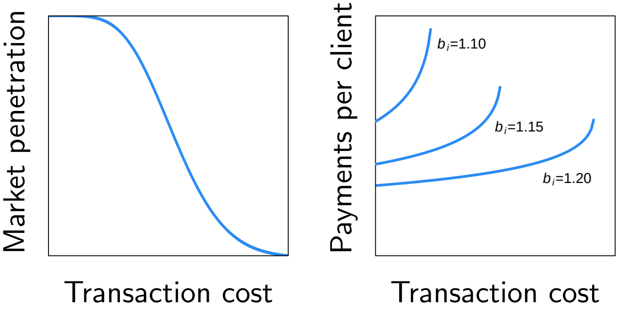
Transaction Costs and the Frequency of Payments

Extensive Margin | Intensive Margin | Full Relationship



Transaction Costs and the Frequency of Payments

Extensive Margin | Intensive Margin | Full Relationship



Transaction Costs and the Frequency of Payments