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# Optimal design and ownership structures of innovative retail payment systems

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# Optimal Design and Ownership Structures of Innovative Retail Payment Systems

*Completed Research Paper*

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## Abstract

In response to the Fintech trend, an ongoing debate in the banking industry is how to design the new-generation interbank retail payment and settlement system. We propose a two-stage analytical model that takes into account the value–risk tradeoff in the new payment system design, as well as banks' participation incentives and adoption timing decisions. We find that, as the system base value increases, banks tend to synchronize their investment and adoption decisions. When the system base value is low and banks are heterogeneous, bank association ownership maximizes social welfare. When both the system base value and bank heterogeneity are moderate, government mandate leads to the socially optimal solution. When the system base value is high and banks are relatively homogenous, government ownership is socially optimal. We offer important policy implications regarding the optimal system design and the government regulator's role in shaping the banking industry in future financial innovation.

**Keywords:** Fintech, Payment and Settlement Systems, Economic Incentives, Mechanism Design, Analytical Modeling

## Introduction

Technology is reshaping the landscape of retail payments. Payment innovations such as Square, Apple Pay, AliPay, and PayPal are flourishing. They make transactions convenient and easy, provide tailored services for e-commerce, and spur the growth in retail payment volumes. These new financial technology (FinTech) solutions are quickly gaining market momentum. For example, in April 2019, PayPal announced that it has 277 million user accounts across 202 countries worldwide, handling a total payment volume of $161 billion per quarter;[1] and AliPay has over 700 million annual active users by September 2018, indicating an increase of more than 200 million year on year.[2]

The emergence of new FinTech payment solutions have set new expectations for timely payment settlement to meet the needs of consumers and businesses, challenging the traditional interbank retail payment settlement system, in which payments are accumulated for end-of-day netting, known as deferred net settlement (DNS). DNS unavoidably leads to delay in settlement and thus freezes a large amount of money in the post-trade process. When new technologies enabling Fintech innovators and non-bank competitors to enter the payment and settlement industry, in order to defend their central market position in this long-standing territory, banks are actively pursuing the implementation of new technologies to expedite settlement and ease transactions.

Thus far, different entities have taken different actions to enhance interbank retail payments and settlement services around the world, including the upgrade of existing infrastructure or building new infrastructure

[1] https://www.cnbc.com/2019/04/24/venmo-has-40-million-users-paypal-reveals-for-first-time.html

[2] https://www.pymnts.com/news/mobile-payments/2018/alipay-users-ant-financial-blockchain-ai-iot/

to expedite settlement speed and add state-of-art features supporting innovative payments such as mobile payments. In some countries, the policy makers such as the central bank take charge. This is called *government ownership* structure. For example, In China, the Internet Banking Payments System (IBPS), which offers real-time retail payments settlement, is regulated by People's Bank of China and operated by China National Clearing Centre. In U.S., the Fed started an initiative in 2015 for improving the U.S. payment system with a dedicated task force for faster payments.[3] The project has since reached several milestones with an improved payment system still in progress.

In other cases, major banks and financial institutions formed an association and responded to the need for change. This is called *private ownership* structure. For example, the New Payments Platform (NPP) of Australia is the new fast retail payment system built by a consortium of Australian financial institutions. Also, Bankgirot, jointly owned by the Swedish banks, is the only clearing house for retail payments in Sweden. It managed and developed the mobile payments solution Swish, and launched a new payment system, Payments in Real Time (PRT), in 2012 under competitive pressure from non-bank payment providers.[4]

In addition to the different ownership structures, there is ongoing debate regarding how the innovative retail payment services should be deployed. Not only that the innovations require substantial infrastructure investments, but the scope and timing of adoption, as well as the design characteristics of the innovative payment services, vary across jurisdictions. Different environments, competitive pressure and business needs would influence when and in what form the innovative retail payment services emerge. Table A1 in the Appendix provides some examples of advanced retail payment system innovations in leading countries.

In this research, we study how banks should build their innovative retail payment and settlement services in response to the FinTech trend. We propose a two-stage analytical model to compare the design and performance of innovative retail payment systems under two types of ownerships, namely, the government ownership and private ownership. We examine the optimal system design and banks' participating incentives and timing decisions. We aim to answer the following questions: What are the optimal system configurations, in terms of system capacity to support innovative payments, under each ownership structure? What are banks' participating incentives and strategies under each ownership structure, given that banks have heterogeneous capabilities of handling liquidity risk in settlement? What are the policy implications of the different ownership structures? When would bank associations be more effective in aligning banks' economic incentives? And under what conditions would government mandate lead to socially optimal outcomes?

We identify three types of equilibrium, and under each we derive the optimal system design and corresponding participation strategies of banks. We find that, when the system is designed with low capability, banks with low liquidity cost will participate in the early stage of system building, while banks with high liquidity risk will not use the system even if it is offered for free in the later stage. When the system is designed with medium capability, banks with low liquidity risks will participate in the early stage of system building, and banks with high liquidity risk will adopt the system in the later stage, by paying appropriate fees if the system is under private ownership. Finally, when the system is designed with high capability, all banks will synchronize their timing of participation and collectively engage in the new system development in the early stage. Our analysis shows that, regardless of the ownership type, when the value of payment service increases, the owner will always try to attract more banks to participate at an earlier time, and the total payoff of the new system will always increase. The optimal system capacity chosen by the owner, however, does not monotonically increase in the system value. When the system base value is relatively high, we find that the owner will deliberately build a system with lower capacity, in order to balance the high risk banks' costs and thus to encourage them to join the innovation.

We further identify some exogenous factors that play an important role in the system design. We find that the heterogeneity of banks matters. It can have direct implications for the system liquidity and performance. The system owner must carefully take into account the variation in banks' tolerance for liquidity risk in optimizing the system design. More specifically, when banks in the underlying financial ecosystem are more similar, the owner should build the system with higher capability, supporting more innovative payment features and faster settlement, and should incentivize more banks to participate or co-build this system. In

[3] https://fedpaymentsimprovement.org/faster-payments/
[4] http://www.autogiro.se/en/about-bankgirot/about-us/bankgirots-history/

addition, when banks are quite homogeneous, private ownership is suboptimal compared with the government ownership, but when banks are very heterogeneous, private ownership achieves socially efficient outcome. That is because in the latter case, the private bank association can always employ the proper price to exclude or encourage the participation of some high-risk banks.

Finally, we evaluate the operational and economic efficacy and the implications of each ownership structure to shed light on the related policy issues. Our results suggest that, under some conditions, it is socially optimal to have government intervention for a successful transformation of the retail payment and settlement system. For example, when banks are moderately different in their capability to handle liquidity risk, we propose the government mandate policy that can effectively orchestrate banks' actions and align their incentives to co-invest in a system with faster settlement speed and more innovative features, and thus help banks better respond to the FinTech new comers' competition.

We organize the rest of the paper as follows. Section 2 provides relevant literature review. Section 3 describes our model setup. Section 4 formulates and analyzes the decision-making problem under each ownership structure. Section 5 presents our main results and insights. In Section 6, we summarize our findings and discuss some policy implications.

## Literature Review

Several streams of literature are closely related to our work: interbank payment and settlement systems design, FinTech innovation, and technology adoption. We briefly review the related literature in each of these areas.

Core interbank payment systems are usually classified as either "large-value" or "retail" payment systems, depending on the primary types of transactions (CPSS 2011, 2012). Because large-value payment systems play a key role in the financial economy, many central banks have adopted the real-time gross settlement (RTGS) systems (e.g., Fedwire), which eliminate the credit risk between participants by allowing for the final and irrevocable settlement of each payment (Kahn and Roberds 2001). Because each payment has to be settled on a gross basis, RTGS systems are very demanding in terms of liquidity. To save liquidity, small-value retail payments are normally processed using deferred net settlement (DNS) systems (e.g., the Automated Clearing House system), in which payments are settled periodically on a net basis (Johnson et al. 2004). Only recently, the exponential growth of retail volume and value, together with the desire for FinTech innovation, has called for a transformation in the design of retail payment and settlement systems worldwide (Tompkins and Olivares 2016).

An emerging stream of FinTech research studies a variety of innovative technology applications in the financial industry (Ancri 2016). Most of these studies focus on understanding the economic value and risk of FinTech innovations and examining their disruptive impact on the traditional financial institutions and banks. For example, Allison (2016) documents banks' adoption of blockchain technology and their evaluation of the technological effectiveness in facilitating trade of debt instruments. Bohme et al. (2015), Evans (2014), and Maloumby-Baka and Kingombe (2015) examine the adoption of Bitcoin in the remittance services from the cost and benefit perspective and evaluate its competition effects on banks in this market. As another example, peer-to-peer (P2P) lending is one of the most prominent innovations in consumer finance. A number of positive economic effects have been identified. Balyuk and Davydenko (2016) provide evidence that the screening ability of investors in P2P lending is better than traditional credit intermediaries, which is consistent with the view that public markets can be superior to financial intermediaries in providing funding (Allen and Gale 1999). Jefery and Arnold (2014) highlights inefficiencies and frictions that P2P lending can overcome or mitigate. And many others (Duart et al. 2012, Michels 2012) report evidence that additional soft information arises in P2P lending and thus reducing the extent of information asymmetry in the traditional consumer lending market. Almost all recent FinTech research suggests that the benefits of such disruptive technologies outweigh the associated costs, and hence impose potential threats to traditional bank services. However, there is almost no guidance about how traditional banks can effectively respond to such challenges. Our research contributes to this literature by explicitly modeling banks' strategic reaction to the FinTech trend and shows how the business value and social welfare can be improved if banks choose to actively invest in the new technology to improve their financial service capabilities.

Following the FinTech trend, some recent research has studied the innovative payments and settlements system. Liu et al. (2015) examine recent changes in the payment sector. They apply technology ecosystems and paths of influence analysis to explain the development of mobile payments. They show that both competition and cooperation always coexist among financial institutions during the mobile payments evolution process, and suggest the importance of regulatory roles in driving or delaying such innovation. Khapko and Zoican (2016) claim that the current settlement process features several days of delay and thus is inconsistent with the fast-paced market, while immediate settlement over-emphasizes the counterparty risk and leads to sub-optimal liquidity on banks. They thus propose a "smart settlement" design, which allows counterparties to determine flexible time-to-settlement on a trade-by-trade basis. In addition, Guo et al. (2015) also recognize the drawbacks of both the DNS and RTGS designs for retail payments. They propose a hybrid faster payments settlement system that relies on a centrally managed priority queue to achieve superior settlement efficiency. The new settlement mechanism is able to balance the benefits of fast settlements and the increased liquidity pressure associated with more frequent settlements. Using large scale simulation and controlled experiments, they show that the proposed settlement system can effectively reduce delay cost, improve liquidity utilization, and minimize operational cost.

Our paper also relates to the literature on technology adoption. One prominent theory for adoption model is the technology, organization, and environment (TOE) framework by Tornatzky and Fleischer (1990). They argue that an organization's technological innovation decision making depends on three aspects: the organization's idiosyncratic characteristics, the technological context (such as the risk and value of the specific technology), and external environment (such as industry structure and government regulation). We have considered all these aspects in our study. Kim et al. (2007) develop the value-based model to explain the adoption of Mobile Internet as a new information and communication technology from the value maximization perspective. Hannan and McDowell (1984) and Saloner and Shepard (1995) examine banks' technology adoption behavior. They find that larger banks and banks operating in more concentrated markets have a higher probability of adopting the automatic teller machine. Clemons and Weber (1996) show that the regulatory environment shapes banks' adoption decision of alternative security trading systems. Several other research papers further investigate the optimal timing of technology adoption (Katz and Shapiro 1984, Farzin et al. 1998, Choi and Thum 1998). They show that multiple factors, such as uncertainties about the speed of innovation arrival, the organization's initial technological attributes, the value of the new technology, strategic interaction in the market, network externalities, and environmental policy commitment, will all affect the adoption strategy and timing decision. Specifically, several works (Nelson et al. 1993, Newell et al. 1999, Kerr and Newell 2003) show that policy-induced adoption could be economically efficient, and thus government regulation together with some special economic instruments, such as tax, tradable permits, or subsidies, should be used to provide incentives for technology adoption.

With the rapid advancement in information technology, many new business models emerge. Recent studies in the Information Systems field have investigated technology adoption in various new contexts, such as open source software development (Peng and Dey 2013), digital health records (Ozdemir et al. 2011), electronic payments systems (Plouffe et al. 2001, Bapna et al. 2011), mobile apps (Jung et al. 2019), and cloud IT services (Retana et al. 2018), to name a few. Our work complements this line of new IT adoption research by studying heterogeneous banks' technology adoption strategy and timing decision, based on value, cost and risk trade-off of the new technology, as well as the banks' interactions among themselves.

## The Model Setup

The initiative of a new retail payment and settlement system aims to provide end-users with instant transaction confirmation, secure payment and settlement service, fast payment processing, and funds availability for the payee. When building an innovative and fast retail payments system, a number of important issues needs to be taken into consideration.

**System Capability.** A key design variable is system capability, which can be measured by payments features and functions in several dimensions such as high speed of settlement, 24x7x365 availability, support for state-of-art payment solutions (e.g., B2B, P2P, mobile, etc.), adoption of ISO20022 standard, and support for authentication, transaction notification and documentation. Please see Table A2 in the Appendix for a list of system capabilities in advanced retail payment systems. We denote $q$ as the system capability. The more payment features and functionalities that are included in the system design, and the faster speed of settlement, the higher the system capability.

**System Value**. Settling a payment request completes the underlying business transaction, releases money that otherwise will be locked in the settlement process, and fulfills end-users' demand. Hence, there is value associated with the payment service completion. Such a value could be both tangible and intangible. For example, when the involved cash is released from the settlement process, it could be used for other investment opportunities, and thus generates monetary value. When the end-user's (individual customer, merchants, etc.) demand is fulfilled and transaction is done, it not only generates business value, but also enhances the relationship between the bank and end-users, and thus brings intangible value to the bank.

In the new payment network, banks mutually benefit from the ability to send and receive payments in a timely fashion, and thus they perceive a common system-wide base value $v$. The magnitude of the base value of payment services is related to factors such as the network-wide, different types of the transaction requests, total number of transactions and the amounts involved in the transaction requests. In reality, this parameter $v$ can be calibrated by the expected benefit of payment services based on the overall transaction types and volume in the payment network.

A high-capability system would better serve the banks' customers and generate higher value. For example, a faster settlement releases the money quickly and thus end users are able to get cash earlier for other opportunities; a settlement system supporting innovative payments models such as mobile payments has a high perceived value due to the convenience offered to users; and the improved payment security creates value for consumers, which, in turn, enhances bank-and-customer relationship and eventually brings higher business value to the banks. Denote the total value from the new retail payment and settlement system as $V(q) = vq$, where $v$ is the base value parameter indicating the benefits related to payment services. We assume the higher the system capability, the higher the total value of the system.

**Cost and Risk.** The payment and settlement system requires a central infrastructure, which connects all participating banks to support faster authorization, clearing, settlement of each money transfer, as well as necessary functional improvements for a more convenient and secure settlement. This could be done through enhancing an existing system or building a brand new system, both requiring a large amount of infrastructure investment cost. We assume the infrastructure cost is a quadratic function of the system capability, $C(q) = \frac{k}{2}q^2$. Parameter $k$ measures sensitivity of the cost increase when the system capability $q$ increases. Based on our industry consultation experience, such fixed infrastructure cost is often equally shared among the parties who collectively build the system.

Once the new system is built, banks incur several types of costs. First, a bank might need to pay fees to access the settlement service, depending on the ownership of the system. For example, when the system is owned by a private bank association, the member banks in the association share the infrastructure cost, and non-member banks often will be charged a participating fee $p$ for using the new settlement services. On the other hand, if the system is owned by the government, the government could charge a fixed annual maintenance fee for each bank using the system; alternatively, the government could also absorb the maintenance cost by itself. In this work, we adopt the second approach; that is, once the system is built, it is provided as public goods to all banks without a fee.

The second type of cost is the liquidity cost in settling payments. Typically, a bank is required to pledge cash collateral into its settlement account held at the central bank. When the money at its settlement account is not enough for payments clearing, liquidity shock occurs. In such a case, the bank will first need to borrow money to support the payment processing and then pay back (with interest) afterwards. This results in liquidity cost for the bank. As the speed of settlement increases, banks are more likely to experience liquidity shocks. This is because an expedited system settles payments requests in a timely manner by shortening the netting cycle. As a result, banks have less opportunity to find offsetting payments that would otherwise be possible in longer netting cycles. Therefore, in a faster settlement system, banks are more likely to encounter liquidity shocks and face higher expected liquidity cost. Based on our review and study of the payments industry, high liquidity cost is the largest concern during the settlement process in practice. Therefore, we model the main operational cost as the liquidity cost (due to liquidity shocks) that is born by each participating bank. We denote the unit liquidity cost as $L$.

In reality, banks are heterogeneous in their ability to meet the liquidity requirements. For example, large banks typically have a huge amount of funds available to maintain the business stability, and their ability to satisfy liquidity demand is typically higher than the small ones which have limited capital and are more likely to incur liquidity shocks. To simplify, we distinguish banks into two types: a $\lambda \in (0,1)$ proportion of banks has the probability of $\theta_l$ to incur liquidity shock, and a $1-\lambda$ proportion of banks has the probability $\theta_h$, and $0 < \theta_l < \theta_h < 1$. We call the former low-risk type and the latter high-risk type. In practice, we can think of large banks the low-risk type and small banks the high-risk type. So, for a bank with type $i$, where $i \in \{h, l\}$, its expected liquidity cost under a system with capacity $q$ is $\theta_i qL$.

Putting all these together, we can write the utility function for bank $i$ as:

$$U_i(q) = vq - p - \theta_i qL. \quad (1)$$

**Decision-making Timeline**. A general-purpose, fast payment and settlement system typically can be constructed and become available in several years. Figure 1 shows a two-stage decision process that characterizes the system design choices and banks' participation timing decisions. At the beginning (time 0), the system owner will determine the retail payment and settlement system capability $q$, start to invest in the infrastructure, and announce a fee structure $(p_1, p_2)$ such that the first-period (earlier) adopters will pay $p_1$ while the second-period (later) adopters will pay $p_2$, and $p_1 \leq p_2$. A bank's decision problem thus is whether to adopt and when to adopt, given its own type and others' decisions.

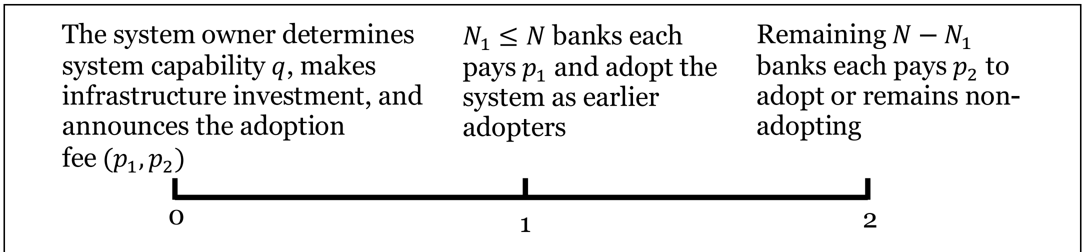


**Figure 1. The Two-Period Decision Making Process**

## Problem Formulation

System ownership is important because the owner may build the system capability that fits his own interests, determine access fees for the service or how revenue should be split among the participating institutions, and thus affect all others' participation incentives. In practice, interbank payment settlement systems can be categorized as either *government systems* or *private sector systems* depending on who owns and operates the systems. The government systems are owned and operated by the central bank, which is also the regulator and monetary authority of the nation. The private sector systems are owned and operated by private sector groups, which in most cases are a bank association or clearing house. In what follows, we formulate the respective owner's system design optimization problem under each ownership structure. We then propose the *government mandate policy*. Our purpose is to investigate whether and how such a policy would affect the equilibrium outcomes, and under what conditions the government mandate is necessary to reach a socially optimal solution.

### *System Design under Government Ownership (GO)*

The government regulator (the central bank) is a social planner, who aims to maximize the total social welfare. To build a system with government ownership, in practice, it first will call for participation of major banks. The infrastructure cost is shared among these banks. Once a payment and settlement system has been built, the government will provide it as a national public service to all banks in the financial ecosystem. That is to say, $p_1 = \frac{k}{2N_1} q^2$, where $N_1$ is the number of banks that participate in the initial system building stage; and $p_2 = 0$. In the following, we normalize $\theta_h = 1$ and simplify notation as $\theta_l = \theta < 1$. Also, we assume $v > \theta L$ to ensure that at least for low-risk banks the value of the new system is higher than the associated liquidity cost, so that they have incentive to use it. The central bank has three strategies:

***Strategy GO1:*** The central bank sets the system capability such that only low-risk banks will participate in the initial system building. High-risk banks have no incentive to participate at all, even if in stage 2 it is free to join ($p_2 = 0$). Let $\delta$ be the discount factor. The regulator's problem is:

$$max_q \ \ (1+\delta)N_1[vq-\theta qL]-\frac{k}{2}q^2 \tag{2}$$
$$\text{s.t.} \quad (1+\delta)[vq-\theta qL]-p_1 \geq 0 \tag{3}$$
$$vq-Lq<0 \tag{4}$$
$$p_1=\frac{k}{2N_1}q^2;\ N_1=\lambda N$$

The objective function (2) is the total value of the system across the two periods subtracts the total infrastructure cost and liquidity-related operational cost.[5] Constraint (3) ensures that the low-risk bank has proper incentive to invest in the first period. Constraint (4) ensures that the high-risk bank has no incentive to join in the second period even though the system is free to use.

***Strategy GO2:*** The central bank sets the system such that only low-risk banks will participate in the system building in the first stage. High-risk banks will participate in stage 2 once the system has been built and provided as public goods ($p_2 = 0$). The regulator's problem is:

$$max_q \ \ (1+\delta)N_1[vq-\theta qL]+\delta(N-N_1)[vq-qL]-\frac{k}{2}q^2 \tag{5}$$
$$\text{s.t.} \quad (1+\delta)[vq-\theta qL]-p_1 \geq 0 \tag{6}$$
$$vq-qL \geq 0 \tag{7}$$
$$(1+\delta)[vq-qL]-p_1<\delta[vq-qL] \tag{8}$$
$$p_1=\frac{k}{2N_1}q^2;\ N_1=\lambda N$$

In the objective function (5), the first term is the net utility from low-risk banks across the two periods, the second term is the discounted net utility from high-risk banks in the second period, and the last term is the system investment cost. Constraint (6) is the low risk banks' incentive compatibility constraint. Constraints (7) and (8) are the high-risk bank's incentive compatibility constraints: they ensure that a high-risk bank would prefer to wait until the second period for a free system access.

***Strategy GO3:*** The central bank sets the system features that induce both high- and low-risk banks to jointly build the system in the first period. The regulator's problem is:

$$max_q \ \ (1+\delta)N_1[vq-\theta qL]+(1+\delta)(N-N_1)[vq-qL]-\frac{k}{2}q^2 \tag{9}$$
$$\text{s.t.} \quad (1+\delta)[vq-\theta qL]-p_1 \geq 0 \tag{10}$$
$$(1+\delta)[vq-qL]-p_1 \geq 0 \tag{11}$$
$$(1+\delta)[vq-qL]-p_1>\delta[vq-qL] \tag{12}$$
$$p_1=\frac{k}{2N}q^2;\ N_1=\lambda N$$

In the objective function (9), the first two terms are the total utility from low- and high-risk banks across the two periods respectively, and the last term is the total investment cost. Constraint (10) and (11) ensure that the both types of banks will invest in the first period. Note that constraint (11) always dominates (10). Constraint (12) ensures that the high-risk bank has no incentive to wait to join in the second period.

## *System Design under Private Ownership (PO)*

Under the private ownership, several major banks form an association. They co-build the infrastructure, jointly own the new system, and charge a fee for non-member banks to use the new payment services. The association aims to maximize their member banks' total payoffs. It has two strategies:

***Strategy PO1***: Low-risk banks form the bank association and build the new system in the first period for its exclusive use. It charges a high price $p_2$ to strategically exclude the high-risk banks from joining the system in the second period. The bank association's optimization problem is:

$$max_{p_2,q} \ \ (1+\delta)N_1[vq-\theta qL]-\frac{k}{2}q^2 \tag{13}$$

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5 Through the interviews with industry experts, we learned that once the system is built, it relies on automatic algorithms to match and settle payments at a pre-specified frequency. The system maintenance cost is relatively insignificant as compared to the infrastructure cost and liquidity cost. We thus do not model the system maintenance cost. Including such a (small) cost component in the owner's optimization problem won't affect our results qualitatively.

$$\text{s.t. } (1+\delta)[vq-\theta qL]-\frac{k}{2N_1}q^2 \geq 0 \quad (14)$$
$$vq-qL-p_2<0 \quad (15)$$
$$N_1=\lambda N$$

Comparing it with GO1, the only difference is that there is an extra term $p_2$ in the high-risk bank's participation constraint (15). If $v<L$, then even if the new system is free (i.e., $p_2=0$), high-risk banks are not interested in adopting it. If $v>L$, constraint (15) states that the system owner excludes high-risk banks from using the new system by strategically setting a high enough participation fee.

***Strategy PO2:*** Low-risk banks form the association and build the new system in the first period. In the second period, high-risk banks use it by paying a fee $p_2$. The bank association's optimization problem is:

$$max_{p_2,q} \quad (1+\delta)N_1\{vq-\theta qL\}+\delta(N-N_1)p_2-\frac{k}{2}q^2 \quad (16)$$
$$\text{s.t.} \quad (1+\delta)[vq-\theta qL]+\delta\frac{N-N_1}{N_1}p_2-\frac{k}{2N_1}q^2 \geq 0 \quad (17)$$
$$vq-qL-p_2 \geq 0 \quad (18)$$
$$N_1=\lambda N$$

In the objective function (16), the first term is the net utility from low-risk banks across the two periods. The second term is the discounted payments from high-risk banks in the second period. The last term is the total investment cost. Constraint (17) ensures that the low-risk bank in the association has incentive to invest in building the new system. The payments $(N-N_1)p_2$ received in the second period will be equally shared by the $N_1$ low-risk banks in the association. Constraint (18) ensures that the high-risk bank has incentive to join the system in the second period. If $v<L$, then the bank association must offer subsidy (i.e., $p_2<0$) in order to motivate high-risk banks to adopt their system, which would not be optimal as it reduces the bank association's net profit. If $v>L$, then in the optimal solution, the high-risk banks' participation constraint (18) will always be binding, because the system owner will charge a positive fee $p_2$ to extract all surplus from them. Hence, we have $p_2=vq-Lq$.

## *System Design under Government Mandate (GM)*

Sometimes, the government and private banks don't hold the same view. For example, the central bank sees the need to move to an advanced new payment system for a nation's strategic consideration such as global competitiveness, but individual banks are not willing to do so due to liquidity concern. To examine what would happen in the presence of such conflict and to see what government can do to push the payment innovation process, we propose the government mandate strategy: the regulator (the central bank or monetary authority in a nation) mandates the migration to a new payments system. That is, both high- and low-risk banks are mandated to jointly build the system, share the total infrastructure cost, and adopt the new system use. These are the questions we aim to answer: Whether and when such a government mandate strategy is beneficial and appropriate, helping achieve the socially optimal solution? How would it affect different banks' payoffs? Will it impose serious issues on banks' business stability?

***Strategy GM:*** The optimization problem under the Government Mandate (GM) policy is:

$$max_q \quad (1+\delta)\lambda N[vq-\theta qL]+(1+\delta)(1-\lambda)N[vq-qL]-\frac{k}{2}q^2 \quad (19)$$
$$\text{s.t.} \quad (1+\delta)[vq-\theta qL]-\frac{k}{2N}q^2 \geq 0 \quad (20)$$
$$(1+\delta)[vq-qL]-\frac{k}{2N}q^2 \geq 0 \quad (21)$$

Note that the objective function (19) in Strategy GM is the same as that in Strategy GO3. The regulator maximizes the total social welfare. Constraints (20) and (21) ensure the two-period net benefits of the low-risk and high-risk banks are non-negative. The difference between GM and GO3 is that, under government mandate, high-risk banks do not have the choice to wait till the second period for adoption because they are required to collectively build the new system together with the low-risk banks in the first period. The reason we still impose constraints (20) and (21) is because otherwise some banks might be mandated to participate for a loss, which might lead to systemic risk and would be detrimental to the stability of the whole financial system. The participation incentives still should be satisfied to ensure the public policy objective.

## Analysis and Results

All parties' decision-making is endogenous. The system owner determines the optimal system design, taking into consideration banks' corresponding participation incentives; and banks make decisions on whether and when to participate in the infrastructure building and the use of the new system, given the system owner's design choice. In this section, we first present the equilibrium outcomes under the government and private ownership structure, respectively. We then compare different ownership structures and examine the impact of the mandate policy on optimal system capacity and social welfare.

### *Government Ownership*

When the government designs the new system, we derive the following equilibrium outcome.

**Proposition 1.** Under the government ownership, the optimal system capacity and banks' corresponding participation strategies are:

(1) If $\theta L < v \leq v_1$, the optimal system capacity is $q^*_{GO} = \frac{(1+\delta)\lambda N}{k}(v - \theta L)$. The equilibrium participation strategy for banks is *GO1*: Low-risk banks build and use the new system, while high-risk banks completely stay out of this innovation process.

(2) If $v_1 < v \leq v_2$, the optimal system capacity is $q^*_{GO} = \frac{(1+\delta)\lambda N(v-\theta L)+\delta(1-\lambda)N(v-L)}{k}$. The equilibrium participation strategy for banks is *GO2*: Low-risk banks build the system and use it afterwards, while high-risk banks will adopt the new system after it is provided as free public goods.

(3) If $v_2 < v \leq v_3$, the optimal system capacity is $q^*_{GO} = \frac{2N(v-L)}{k}$; and if $v > v_3$, the optimal system capacity is $q^*_{GO} = \frac{(1+\delta)\lambda N(v-\theta L)+(1+\delta)(1-\lambda)N(v-L)}{k}$. The equilibrium participation strategy for banks is *GO3*: Both low-risk and high-risk banks participate in the system building and use.

The threshold values are given by $v_1 = L$, $v_2 = \frac{2-\delta(1-\lambda)-\lambda\theta(1+\delta)+2\sqrt{1-\lambda}}{2-\delta-\lambda+2\sqrt{1-\lambda}}L$, $v_3 = \frac{2-(1+\delta)(1-\lambda+\lambda\theta)}{1-\delta}L$, and $v_1 < v_2 < v_3$. Figure 2 graphically demonstrates Proposition 1.

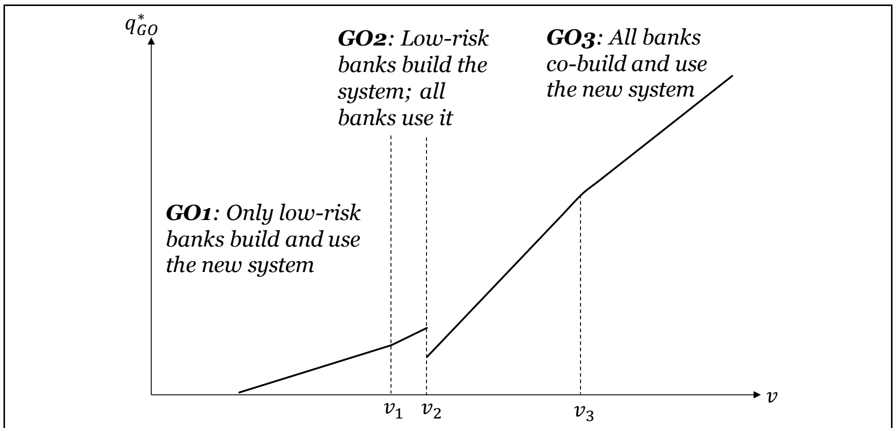


**Figure 2. The Optimal System Capacity and Strategy under Government Ownership (GO)**

The solid lines in Figure 2 indicate the optimal system capacity under the government ownership. There are three regions. When the system base value is relatively small, $v \leq v_1$, the equilibrium strategy is GO1 and only low-risk banks develop and use the new system while high-risk banks are left out of this innovation game. When the base value of the system is in an intermediate range, $v_1 < v \leq v_2$, the equilibrium strategy is to let the low-risk banks to build the system in the first period and invite high-risk banks to use the services for free in the second period. When the base value is high enough, $v > v_3$, the optimal strategy is to induce all banks to co-build the system in the first period. Thus, as the base value of the system increases, the central bank should strategically set the system capacity at appropriate levels to motivate more banks to participate in and contribute to the financial innovation at an earlier time.

An interesting observation is that the optimal system capacity does not necessarily increase in the base value of payment services monotonically, though it does demonstrate a general upward trend as $v$ increases. Note that there is a significant drop in the system capacity at the tipping point $v_2$, beyond which synchronized co-investment in the new infrastructure and immediate mass adoption from all participants occur. The discontinuity occurs at $v_2$ when the strategy switches from GO2 to GO3. The difference between the two strategies is that only low-risk banks build a high-capability system under GO2 whereas both low- and high-risk banks collectively build a relatively low-capability system under GO3. As the system base value increases, the system owner tends to build a high capacity system under GO2. However, as the system capability increases, the associated liquidity risk and operating cost increase as well. Under GO3, to encourage high-risk banks to co-build the new system in the first stage, instead of just using the system after it is built, the system capability cannot be set too high, thus a dip at $v_2$. Although the system capacity is reduced around $v_2$, the social welfare under GO3 is higher than that under GO2 when $v > v_2$, and therefore, the optimal strategy switches from GO2 to GO3.

Moreover, the composition of the underlying banking industry is another factor that the system owner takes into consideration in the optimal system capacity design. Recall that the parameter $\lambda$ is the proportion of low-risk banks in the population. A large $\lambda$ represents a concentrated financial ecosystem where there are more large banks with sufficient liquidity supply, while a small $\lambda$ suggests a diverse financial ecosystem with many small banks, which are more likely to be liquidity constrained. Our findings suggest that, all else being equal, if the banking industry is more concentrated, i.e., a large $\lambda$, the regulator will choose to build a more capable system (e.g., faster settlement speed and more innovative features).

## *Private Ownership*

Under the private ownership structure, a group of major banks are the owner of the system. The system owner's decision-making problem under the two strategies (i.e., PO1 and PO2) has been formulated in the previous section. We solve for the equilibrium and obtain the following results.

**Proposition 2.** Under the private ownership, the optimal system capacity, price, and banks' corresponding strategies are given as below.

(1) If $v \le v_1$, the optimal system capacity is $q_{PO}^* = \frac{(1+\delta)\lambda N}{k}(v - \theta L)$. The equilibrium strategy is *PO1*: Low-risk banks build the new system, and charge a price $p_{PO}^* = \max\left[(v - L)\frac{(1+\delta)\lambda N}{k}(v - \theta L), 0\right]$ to exclude the high-risk banks from using the new system.

(2) If $v > v_1$, the optimal system capacity is $q_{PO}^* = \frac{(1+\delta)\lambda N(v-\theta L)+\delta(1-\lambda)N(v-L)}{k}$. The equilibrium strategy is *PO2*: Low-risk banks build the new system, and charge a positive price $p_{PO}^* = \frac{(1+\delta)\lambda N(v-\theta L)+\delta(1-\lambda)N(v-L)}{k}(v - L)$ for high-risk banks to use the new system.

Figure 3 compares the optimal system capacity and the equilibrium strategy under different ownership structures. The solid (dashed) lines in Figure 3 depict the optimal system capacity under the government (private) ownership structure. When $v < v_2$, the dashed lines overlap with the solid lines. Different from the government ownership, there is no discontinuity point under the private ownership.

In the region $v \le v_1$, the private system owner takes Strategy PO1, which is equivalent to GO1. Namely, low-risk banks will build and use the new system exclusively. Under PO1, even if the new system is free to use, high-risk banks are not interested in adopting the system. The fact that Strategy GO1 overlaps PO1 in this range suggests that the two ownership structures yield the same configuration of system capacity and result in the same level of total payoff when the base value of the system is low.

In the region $v_1 < v \le v_2$, the private system owner takes Strategy PO2, which, again, yields the same optimal capacity level as GO2. However, the underlying mechanism is fundamentally different. Under the private ownership, the bank association builds the system and charges a fee for those non-member banks to access it. It resembles a commercial market where member banks sell innovative payment services to the non-member banks at a positive price. Under the government ownership, all banks use the services offered by the government for free, so there is no market. In contrast to the government ownership under which high-risk banks earn positive utility, under the private ownership, low-risk banks in the bank association extract all surplus from (non-member) high-risk banks. Such a fee represents an internal value transfer among banks, and therefore, the total social welfare is the same under the two structures.

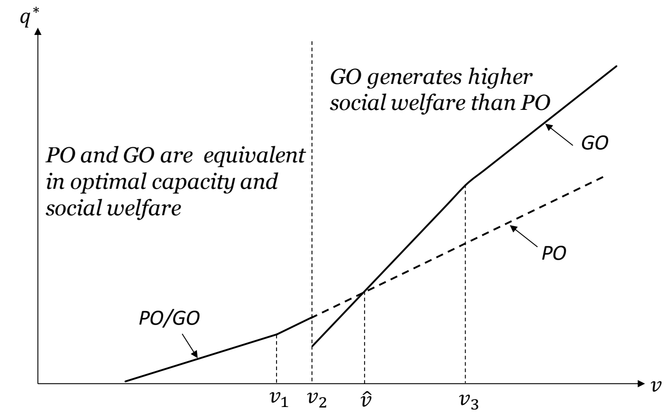


**Figure 3. Comparison of the Optimal System Capacity and Strategy between Private Ownership (PO) and Government Ownership (GO)**

In the region $v > v_2$, the equilibrium strategy under private ownership is PO2, and the system capacity may be higher or lower than that in GO3 under the government ownership. The social welfare under private ownership is always lower than that under government ownership. When $v < \hat{v}$, the government would set a relatively low capacity so that high-risk banks would not perceive the investment too risky, and thus be willing to co-build the system together. However, the private bank association, for its own interest, chooses to set the system capacity high so that it can charge a high price for the non-member banks to use it. When $v > \hat{v}$, because the base value of the system is high enough, the regulator would choose to attract all banks to build a high-capacity system. However, the private bank association deliberately sets the capability lower than the social optimum for its self-interest to maximize member banks' private benefits. Since the increased infrastructure cost cannot be compensated by the increased price paid by the non-member banks, the bank association decides to build the system capacity level lower than the social optimum.

## *Government Mandate*

Next, we explore the Government Mandate (GM) policy, meaning that the government, through relevant financial regulations, requires all banks to participate in the payment and settlement innovation. It is unclear whether such regulation indeed supports or hurts the economy as a whole. In what follows, we will examine how the GM strategy would potentially affect the equilibrium capacity of the new payment and settlement system as well as the total social welfare. We solve the regulator's decision-making problem under the GM strategy and get the following result:

**Proposition 3.** 1) When the base system value is small, $v < v_1$, the GM strategy is socially inefficient.

2) If $v_1 < v \leq v_4 \equiv L(1 + \lambda - \lambda\theta)$, then the optimal system capacity under GM is $q^*_{GM} = \frac{2N(1+\delta)(v-L)}{k}$.

3) If $v > v_4$, then the optimal system capacity under GM is $q^*_{GM} = \frac{(1+\delta)\lambda N(v-L\theta)+(1+\delta)(1-\lambda)N(v-L)}{k}$.

Since $q^*_{GM} \geq 0$, we first note that the GM strategy is infeasible if the base value even cannot cover the liquidity cost for high risk banks ($v < v_1 = L$). The government should not set any regulation to require all banks to act together to build the new system. Instead, the participation decision needs to be left to each individual bank. In this case, high-risk banks will choose to stay out of the financial innovation process.

When $v > v_1$, we are interested in examining whether and when the GM strategy improves social welfare. Since the government ownership (GO) can always generate the same or higher social welfare than the private ownership (PO), in what follows, we will use GO as the benchmark. Our results show that it may or may not be socially optimal for the regulator to mandate all banks to take the same action together. We find:

**Proposition 4.** The GM strategy improves total social welfare when $\tilde{v} < v < v_3$. More specifically:

1) If $\tilde{v} < v < v_2$, then the socially optimal capacity under government mandate is lower than that under the government ownership: $q^*_{GM} < q^*_{GO}$.

2) If $v_2 < v < v_3$, then the socially optimal capacity under government mandate is higher than that under the government ownership: $q^*_{GM} > q^*_{GO}$.

We find that, from a social planner's perspective, the GM strategy should be adopted only when the base value is in intermediate range ($\tilde{v} < v < v_3$). Figure 4 illustrates the optimal system capacity under the government and private ownership structures, as well as the government mandate policy.

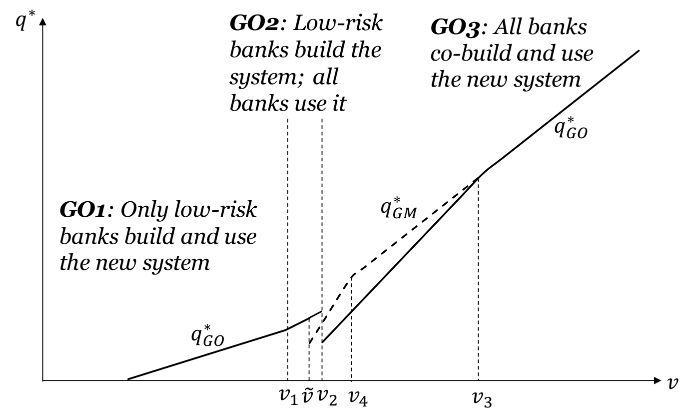


**Figure 4. When Government Mandate is Socially Optimal**

Recall that $v_2$ is a critical tipping point beyond which synchronizing investment among all players and immediate mass adoption would occur under government ownership. If $\tilde{v} < v < v_2$, we suggest that the government regulator should play a coordinating role by executing the GM strategy. Under government mandate, low-risk banks accommodate with high-risk banks to build a system with lower capability ($q^*_{GM} < q^*_{GO}$) so that the mass adoption tipping point is pushed earlier, from $v_2$ to $\tilde{v}$.

If $v_2 < v < v_3$, we also recommend government mandate. Without it, the system capacity under the GO structure is set lower than the socially optimal level. This is because otherwise the very high system operating cost will induce high risk banks to push their adoption decision to the second period, rather than co-build the system in the first period. Under GM, however, high-risk banks have no such a choice. Overall, under GM, low-risk banks are better off and high-risk banks are worse off. The overall social welfare improves due to the higher system capacity.

## *Impact of Bank Heterogeneity on Optimal Strategy*

In our model, banks are heterogeneous in the expected liquidity costs incurred during the settlement process. Denote $\rho = \frac{v-L}{v-\theta L}$ as the indicator of the heterogeneity level between high-risk and low-risk banks. Because $0 \le \theta \le 1$, we have $\frac{v-L}{v} \equiv \underline{\rho} \le \rho \le 1$. As $\theta$ increases, $\rho$ also increases. The higher the $\rho$ value, the more homogeneous banks are in the financial ecosystem. Also note that $\rho < 0$ when $v < L$.

We find that banks' heterogeneity level $\rho$ plays an important role in determining the optimal system capacity, and thus affects the final market equilibrium outcome. Figure 5 depicts our findings.

There are three critical values in Figure 5, $\tilde{\rho} < \rho^* < \bar{\rho}$. Above the $\rho$ line, we show the equilibrium strategies under both types of ownership. Clearly, when banks in the underlying financial ecosystem are more similar, the regulator would be more likely to induce them to participate in the system building and adopt new system together. As Figure 5 shows, when banks' heterogeneity reduces (i.e., $\rho$ increases), the equilibrium strategy under GO structure will move from GO1, to GO2, and eventually to GO3. If banks are quite different (i.e., a small value of $\rho$), it might be too costly to let them act in the same way at the same time: in order to motivate high-risk banks to co-build or use the system, the regulator may have to set a very low system capacity to make sure these banks can cope with the associated costs. Such a reduction in the system capacity, however, will also reduce the total social welfare and thus is not preferred by the regulator.

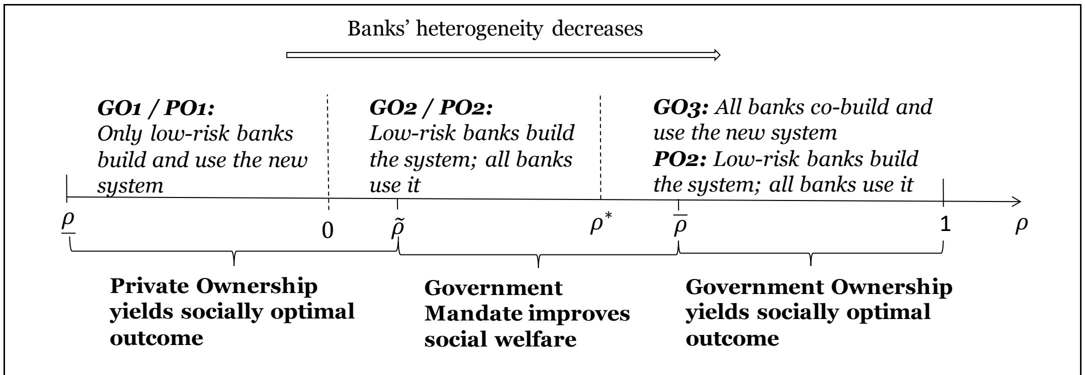


**Figure 5. Equilibrium Strategy vs. Banks' Heterogeneity**

Below the $\rho$ line in Figure 5, we indicate the optimal ownership structure. We have the following result:

**Proposition 5.** 1) If $\rho < \tilde{\rho}$, the private ownership is as efficient as the government ownership, both maximizing social welfare, and there is no need for government mandate.

2) If $\tilde{\rho} < \rho < \bar{\rho}$, the government mandate improves total social welfare.

3) If $\rho > \bar{\rho}$, the government ownership is as efficient as the government mandate, both maximizing social welfare, and there is no need for government mandate.

We offer several interesting policy recommendations. First, when banks in the financial industry are highly heterogeneous, $\rho < \tilde{\rho}$, it is infeasible (when $\rho \leq 0$) or socially inefficient (when $0 < \rho < \tilde{\rho}$) to impose government mandate. Instead, it is socially preferred to allow major banks to form association and become the innovation leader in building new systems. Sweden is a good example. There are more than 114 banks in Sweden. The four biggest banks in Sweden account for more than 80% of the industry's total assets. So its bank heterogeneity is high. Currently the Sweden retail payment system, called Payments in Real Time (PRT), is operated by Bankgirot (please refer to Table A1 for detailed features of RPT). Bankgirot is a bank association owned by six of Sweden's largest banks. This is consistent with our finding that, when bank heterogeneity is high, large banks can lead the payment innovation and develop a private system. Private ownership yields the socially optimal outcome.

Second, the GM strategy improves social welfare when the bank heterogeneity is in the intermediate range. When $\tilde{\rho} < \rho < \rho^*$, GM strategy dominates GO2 and PO2 strategies. The regulator mandates high-risk banks to join the new system co-building in the first period, who otherwise will not participate at such an early stage, but instead will only become the late adopters of the new system. In the range of $\rho^* < \rho < \bar{\rho}$, GM strategy dominates GO3 strategy.[6] Although all banks' participation action and timing remain the same under the two strategies, the optimal system capacity under GM is higher than that under GO3. The system will be built with more innovative features and performs faster settlement speed.

When $\rho > \bar{\rho}$, banks are more homogeneous, the GM strategy is not necessary anymore. Banks are very similar, so they will self-select to act at the same time and in the same way. In such a scenario, although the regulator can leave the participation decision to banks themselves (i.e., no need to use GM), the government should lead the financial innovation, because private ownership will lead to a sub-optimal system capability choice compared to the government ownership. This is what we see in Japan. Compared with Sweden, the Japanese banking system, with about 200 banks, has relatively lower heterogeneity. Consistent with our finding, Bank of Japan, the country's central bank, owns and operates the retail payment system Zengin. Please refer to Table A1 for detailed features of the Zengin system and its recent innovations.

[6] The GO3 strategy under GO structure dominates the PO2 strategy under PO structure.

## Discussion and Conclusion

Innovative retail payment systems are one of the most important trends in recent financial innovations in the retail banking industry. We have seen global efforts to use advanced technologies to build the new infrastructure that supports future payment clearing and settlement services. The new systems in different countries vary in terms of ownership, attributes, and architectures. So far, no single best approach has been identified, and the social and economic payoffs of the new payment system innovations are still unknown. We fill this research gap by developing an analytical framework for individual banks, central banks, and government authorities to examine the optimal design of the new infrastructure to support future innovative retail payment systems in the economy. Under both the government and private ownership structures, we analyze the system owner's choice of the optimal system capacity, as well as different banks' technological investment and adoption timing decisions.

We show that different ownership structures result in different optimal system designs. Under private ownership, the optimal system capability monotonically increases in the base value of the new system. In contrast, under government ownership, the optimal system capability does not necessarily increase when the system base value increases. Under both ownership structures, when the system is designed with low capability, banks with low liquidity risks will invest in the new infrastructure, while banks with high liquidity risk will not be interested in the system adoption. When the system is designed with medium capability, banks with low liquidity risks will become early movers to build the new infrastructure, and banks with high liquidity risk will become late adopters. Finally, when the system is designed with high capability, all banks will synchronize their timing of participation and collectively invest and develop the new system.

When the base value of the new system is lower than a threshold, both the private and government ownership structures yield the socially optimal outcome. The private sector can provide a system that is at least as efficient as one provided by the central bank. When the base value of the new system is in the intermediate range, private ownership tends to offer higher system capability than the socially optimal level. The reason is that the government chooses to control the system risk by capping the system capability at an appropriate level. A lower system capability in this case reflects the government's intention to synchronize banks' investment incentives in order to motivate them to participate in this financial innovation process, promote immediate mass technology adoption, and lead to higher social welfare. In contrast, when the base value of the new system is large, private ownership results in fewer innovative features and lower system capability compared to the socially optimal outcome. This finding shows the inefficiency of the monopolistic private ownership structure. The private ownership structure constrains the innovation to less than the full extent of what is technologically possible. In this case, efforts by the government to improve payment system capabilities positively affect the achievement of public policy objectives. Thus, the central bank or government needs to establish rules and regulations to monitor compliance.

In reality, heterogeneity among payment service providers can give rise to coordination challenges. We show that the private ownership is an efficient and socially optimal solution to manage the innovative payment system if the banks' heterogeneity level is high. When banks are quite different, the government could consider letting the large bank association to play the decision-making role. Using the appropriate market mechanism (i.e., the price), the bank association can effectively deter or motivate other banks' participation, generating the equilibrium outcome that aligns the interest of itself as the private owner and the interest of the society as a whole. On the other hand, when banks are relatively homogeneous, the government should consider playing a coordinating role in orchestrating, or even setting rules and regulations to mandate the development and adoption of the new system. The government's coordination leads to earlier mass adoption of the technology innovations and help banks better respond to the FinTech new comers' competition. When heterogeneity is in an intermediate range, it is instrumental for the government to use a mandate policy that requires all banks to co-invest and co-build the new payment infrastructure. As long as the system capability is carefully established at an appropriate level, such policy intervention can improve the social welfare while maintaining the healthy operation of the financial system. These findings provide guidance to the government regulators and policy makers in their promotion of technological innovation to support the future retail payment services and other Fintech innovations.

## References


Allen, F. and Gale, G. 1999. "Diversity of Opinion and Financing New Technologies," *Journal of Financial Intermediation* (8), pp. 68-89.

Allison, I. 2016. "R3 Connects 11 Banks to Distributed Ledger Using Ethereum and Microsoft Azure," *International Business Times*. Available at http://www.ibtimes.co.uk/r3-connects-11-banks-distributed-ledger-using-ethereum-microsoft-azure-1539044. Last retrieved in May 2017.

Ancri, C (2016) Fintech innovation: An overview. Presentation, Board of Governors of the Federal Reserve System, Washington, DC (October 19).

Balyuk, T., and Davydenko, S. 2016. "Peer-to-Peer Lending," *Working paper*.

Bapna, R., Goes, P., Wei, K. K., and Zhang, Z. 2011. "A Finite Mixture Logit Model to Segment and Predict Electronic Payments System Adoption," *Information Systems Research*, (22:1), pp. 118-133.

Bohme, R., Christin, N., Edelman, B., and Moore, T. 2015. "Bitcoin: Economics, Technology, and Governance," *Journal of Economic Perspectives* (29: 2), pp. 213-238.

Choi, J. P. and Thum, M. 1998. "Market Structure and the Timing of Technology Adoption with Network Externalities," *European Economic Review* (42: 2), pp. 225-244.

Clemons, E. K., and Weber, B. W. 19960. "Alternative Securities Trading Systems: Tests and Regulatory Implications of the Adoption of Technology," *Information Systems Research*, (7:2), pp. 163-188.

Committee on Payments and Market Infrastructures (CPMI). 2016. "Fast Payments – Enhancing the Speed and Availability of Retail Payments," Basel, Switzerland: Bank for International Settlements.

Committee on Payment and Settlement Systems (CPSS). 2011. "Payment, Clearing and Settlement Systems in the CPSS countries," Vol. 1, Basel, Switzerland: Bank for International Settlements.

Committee on Payment and Settlement Systems (CPSS). 2012. "Payment, Clearing and Settlement Systems in the CPSS countries," Vol. 2, Basel, Switzerland: Bank for International Settlements.

Duarte, J., Siegel, S. and Young. L. 2012. "Trust and Credit: The Role of Appearance in Peer-to-Peer Lending," *Review of Financial Studies*, (25:8), pp. 2455-2483.

Evans, D.S. 2016. "Economic Aspects of Bitcoin and Other Decentralized Public-Ledger Currency Platforms," *Working paper*.

Farzin, Y. H., Huisman, K. J. M., and Kort, P. M. 1998. "Optimal Timing of Technology Adoption," *Journal of Economic Dynamics and Control* (22: 5), pp. 779-799.

Guo, Z. L., Kauffman, R., Lin, M., and Ma, D. 2015. "Mechanism Design for Near Real-Time Retail Payment and Settlement System," in *Proceeding of the 4 8th Annual Hawaii International Conference on System Science HICSS*.

Hannan, T. H. and McDowell J. M. 1984. "The Determinants of Technology Adoption: the Case of the Banking Firm," *Rand Journal of Economics* (15: 3), pp. 328-335.

Johnson, K., McAndrews, J.J., and Soramäki, K. 2004. "Economizing on Liquidity with Deferred Settlement Mechanisms," *Federal Reserve Bank of New York Economic Policy Review*, (10:3), pp. 56–72.

Jung, J., Bapna, R., Ramaprasad, J., and Umyarov, A. 2019. "Love Unshackled: Identifying the Effect of Mobile App Adoption in Online Dating," *MIS Quarterly*, (43:1), pp. 47-72.

Kahn, C., and Roberds, W. 2001. "Real-Time Gross Settlement and Costs of Immediacy," *Journal of Monetary Economics*, (47: 2), pp. 299–319.

Katz, M. and Shapiro, C. 1986. "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy* (94: 4), pp. 822- 841.

Kim, H., Chan, H., and Gupta, S. 2007. "Value-based Adoption of Mobile Internet: An Empirical Investigation," *Decision Support Systems* (43: 1), pp. 111-126.

Kerr, S. and Newell, R.G. 2003. "Policy-Induced Technology Adoption: Evidence from the U.S. Lead Phasedown," *The Journal of Industrial Economics* (L1: 3), pp. 317-343.

Jefery, P. and Arnold, D. 2014. "Disrupting Banking," *Business Strategy Review* (3), pp. 11-15.

Liu, J., Kauffman, R., and Ma, D. 2015. "Competition, Cooperation, and Regulation: Understanding the Evolution of the Mobile Payments Technology Ecosystem," *Electronic Commerce Research and Applications* (14: 5), pp. 372-291.

Maloumby-Bak, R. C. and Kingombe, C. 2014. "The Quest to Lower High Remittance Costs to Africa: A brief Review of the Use of Mobile Banking and Bitcons," *Working paper*. Available at SSRN: http://ssrn.com/abstract=1769124

Mariana, K. and Marius, A. Z. 2016. "Smart Settlement," *Working paper*.

Saloner, G. and Shepard, A. 1995. "Adoption of Technologies with Network Effects: An Empirical Examination of the Adoption of Automated Teller Machines," *RAND Journal of Economics* (26:3), pp. 479–501.

Nelson, R., Tietenberg, T. and Donihue, M. 1993. "Differential Environmental Regulation: Effects on Electric Utility Capital Turnover and Emissions," *Review of Economics and Statistics* (75: 2), pp. 368–373.

Newell, R. G., Jaffe, A. B. and Stavins, R. N. 1999. "The Induced Innovation Hypothesis and Energy-Saving Technological Change," *Quarterly Journal of Economics* (114: 3), pp. 941–75.

Ozdemir, Z., Barron, J., and Bandyopadhyay, S. 2011. "An Analysis of the Adoption of Digital Health Records under Switching Costs," *Information Systems Research*, (22:3), pp. 491-503.

Peng, G. and Dey, D. 2013. "Research Note—A Dynamic View of the Impact of Network Structure on Technology Adoption: The Case of OSS Development," *Information Systems Research* (24:4), pp. 1087-1099.

Plouffe, C. R., Hulland, J. S., and Vandenbosch, M. 2001. "Richness versus Parsimony in Modeling Technology Adoption Decisions—Understanding Merchant Adoption of a Smart Card-Based Payment System," *Information systems research*, (12:2), pp. 208-222.

Retana, G. F., Forman, C., Narasimhan, S., Niculescu, M. F., and Wu, D. J. 2018. "Technology Support and Post-Adoption IT Service Use: Evidence from the Cloud," *MIS Quarterly*, (42:3), pp. 961-978.

Tompkins, M. and Olivares, A. 2016. "Clearing and Settlement Systems from Around the World: A Qualitative Analysis," Bank of Canada, Discussion Paper No. 14.

Tornatzky, L. and Fleischer, M. 1990. "The Process of Technology Innovation," Lexington, MA, *Lexington Books*.

# Appendix

**Table A1. Examples: Advanced Retail Payment System Features**

| Country | System | Ownership | Availability | Use Cases | Speed |
|---|---|---|---|---|---|
| **Mexico** | SPEI | Central Bank | 24x7 | Business and consumers | Real-time |
| **Japan** | Zengin | Central Bank | 24x7 | Business and consumers | 4 times daily |
| **United Kingdom** | FPS | Bank Association | 24x7 | Business and consumers | 3 times daily |
| **Sweden** | Bankgiro | Bank Association | 24x7 | Consumers | Real-time |
| **Singapore** | FAST | Bank Association | 24x7 | Business and consumers | 2 times daily |

**Table A2. Examples: Advanced Retail Payment System Capabilities**

| System Capabilities | Participant Tools Enabled | End-User Services Enhanced |
|---|---|---|
| Batch files sorting and routing | Error and fraud detection | Intraday reporting for treasury management |
| Item validation and data capture | Automated reconciliation and submission to settlement system | Automated accounts receivable reconciliation |
| Automated messages and reports | Automated messages and reporting | Automated notifications and messages |
| Standardized remittance information vis ISO 20022 | Automated routing of single item for cross-border transactions | ISO-compliant remittance information |
| Fast bilateral and multilateral clearing and settlement | Flexibility for bilateral arrangements | Electronic invoicing |
| 24x7 availability | Real-time monitoring tools | Real-time monitoring tools |
| Interoperability | Corporate participation and interface for messaging and services | Account switching services |