BARRIERS TO NETWORK-SPECIFIC INNOVATION

Antoine Martin and Michael J. Orlando

Revised: September 2005
(First Version: November 2004)

RWP 04-11

Research Division
Federal Reserve Bank of Kansas City

Antoine Martin is an economist and Michael Orlando is a senior economist at the Federal Reserve Bank of Kansas City. This paper circulated previously under the title “Hold-up on a monopoly owned network.” The authors wish to thank Matthew Cardillo, Dino Falaschette, Ed Green, Thor Koeppl, Jamie McAndrews, Neil Wallace, seminar participants at the Conference on the Economics of Payments (Atlanta 2004), the Missouri Economic Conference (Columbia 2004), and the Penn State Macroeconomics seminar for useful comments. The views expressed herein are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Kansas City or the Federal Reserve System.

Martin email: antoine.martin@kc.frb.org
Orlando email: michael.j.orlando@kc.frb.org

Abstract

We examine incentives for network-specific investment and the implications for network governance. We model an environment in which participants making payments over a network can invest in a technology that reduces the marginal cost of using the network. A network effect results in multiple equilibria; either all agents invest and use of the network is high or no agents invest and use of the network is low. The high-use equilibrium can be implemented where commitment is feasible. Where commitment is infeasible, fixed costs associated with use of the network-specific technology result in a hold-up problem that implements the low-investment equilibrium. As a result, governance structures necessary to achieve commitment will be preferred to those necessary merely to achieve coordination. For example, mutual ownership by network users may emerge where users face risks of *ex post* renegotiation. Such a governance structure will also be sufficient to avoid the network effect.

JEL classification: E59; G29; L14; L22
Keywords: Hold-up, Network; Commitment; Payments;

> “[I]f the [Bank of America] controlled the management of the new partnership, it would be doomed to fail. The new organization would have no heart, no spirit, because the new member-owners would not have the same motivation to make the new venture a success. ... [A] new BankAmericard organization, with many more banks participating as member-owners, would expand the card market way beyond anything the Bank of America could imagine.”[1]

1 Introduction

A demand externality is the feature typically highlighted in the analysis of network resources. If use of a network by one participant increases the valuation of network services to others, equilibrium utilization of network assets may remain below the social optimum. Where network utilization is enhanced by some specific investment, however, the network effect may be only one factor depressing network usage. A more conventional hold-up problem may obtain in the absence of commitment. For example, optimal pricing of network usage can prevent network-specific investments that would reduce the marginal cost of using a network.

Underinvestment in network-specific assets can be mitigated through adoption of an appropriate governance structure. In environments where a network can commit to prices, underinvestment implies a profitable opportunity for a coordinator that can overcome the network effect. Coordination will not be sufficient to achieve full investment absent commitment. In such a case, suboptimal investment implies value for governance mechanism that can achieve commitment and thus prevent the hold-up problem.

The case of Visa is illustrative.[2] Bank Americard, the earliest predecessor to the present day Visa card, exhibited characteristics of a network unable to commit to prices. It could be viewed as a network because more users of

---

[1] Chutkow (2001) p. 106.

[2] Cardillo, Martin, and Orlando (2004) discuss the Visa case in more detail.

the card represented greater potential value to merchants accepting it. And the more merchants that would accept the card, the greater was the value to potential users. Bank Americard could also be viewed as unable to commit to prices when it began in 1958. At that time, the product was under exclusive ownership by Bank of America, who was seeking nationwide distribution of their product in the nascent market for revolving credit and payments. Moreover, many potentially profitable expenditures by card-issuing banks would be specific to the network.

Bank of America established Bank Americard Service Corporation in 1966 in order to expand the program outside the state of California.[3] The corporation would license banks outside the state to issue the Bank Americard in their regions. Formation of the service corporation was the first step toward avoiding commitment problems inherent in the market at that time. This progression culminated in 1970 with Bank of America's decision to transfer ownership of the Bank Americard program to licensed issuers of the card.[4] National Bank Americard Incorporated, jointly owned by card-issuing banks, is thus an illustration of a governance structure that emerges for its superior capability to achieve commitment.

The literature on network effects is well established. Initial contributions highlight the demand interdependence that is essential to network environments. Farrell and Saloner (1985) show conditions under which an industry can become 'trapped' in an inferior or obsolete standard. And Katz and Shapiro (1985) show that network demand externalities give rise to multiple equilibria.

Models of two-sided markets provide a more general framework that is particularly well suited to examining pricing on payments networks. Two-sided markets are networks that face demand from two different types of network

---

[3] Mandell (1990) p. 31.

[4] Chutkow (2001) p. 109.

participants. Demand from one side creates an externality for the other. Rochet and Tirole (2003), Schiff (2003), and Wright (2004), among others, show that the network may charge different prices to different sides of the market in order to balance network utilization. Evans and Schmalensee (2005) highlight the importance of different prices for solving the "chicken-and-egg" problem typical to payments networks.[5]

These contributions have been careful to account for pricing implications of market power inherent in network environments. The power associated with specific investments by network participants is not addressed. However, Holmstrom (1982) showed that investment characterized by incomplete contractabilty and interdependent returns is subject to *ex post* renegotiation. This risk of *ex-post* renegotiation can "hold-up" investment. Consequently, Williamson (1985), Klein (1988), and Hart (1995) conclude hold-up provides incentives for integration of interdependent production activities. In practice, however, many financial services remain independent of underlying payments networks.

This paper develops a model that highlights the interrelation of the disincentive to invest in cost-reducing innovation resulting from a network effect and that derivative of a more conventional hold-up problem. Assuming network access is priced at marginal cost, we show a network effect may result in multiple investment equilibria. However, coordination can avoid investment disincentives associated with the network problem if the network can commit to particular prices for network usage. In contrast, where commitment is not feasible, fixed costs of using the network-specific technology will result in hold-up of network-specific investment.

Table 1 summarizes the results of the paper. For each of the cases considered, we compare equilibrium allocations with those achieved by a central

---

[5] "Consumers do not want cards that merchants do not take, and merchants do not want cards that consumers do not have." p. xi.

planner. We show that in equilibrium there can be too little investment as well as, interestingly, too much investment. Finally, we provide conditions such that socially-inferior equilibria are not implemented when network utilization is priced a marginal cost.

Table 1: Summary of Results

Ability to commit to network usage prices	Investment decision	Cost structure of network-specific technology	Price cap on network usage	Elasticity of demand for network usage	Investment equilibrium
possible	decentralized	variable & fixed	no	any value	low & high
”	coordinated	”	”	”	high
not possible	decentralized	”	”	”	low
”	coordinated	”	”	”	”
”	”	variable only	”	”	high
”	”	”	limit for payments received	elastic	high
”	”	”	”	inelastic	low

The analysis rationalizes emergent forms of network governance as mechanisms necessary to achieve commitment and thereby avoid hold-up of profitable investment. For example, where the cost of contracting between network users is sufficiently low, commitment may be achieve through joint ownership of network resources. Such governance arrangements cannot be rationalized as mechanisms necessary to internalize a network externality through coordination. These findings should be of interest to researchers and policy makers concerned with under-utilization of network resources.

The next section specifies the environment and derives the solution to the planner's problem. Section 3 presents an analysis of network-specific investment assuming it is possible for the network operator to commit to usage fees. Section 4 examines participant investment assuming commitment is not possible. We describe a payments network throughout the analysis for ease of exposition and because such a discussion provides the most obvious mapping to the empirical cases discussed in section 5. Nevertheless, these results apply to network environments in general.

2 The environment

The economy is populated by a mass 1 of network participants.[6] Each network participant makes, on behalf of clients, one payment to and receives one payment from each of the other network participants. The total revenue received by the network participant for this activity is a given constant R.[7] Consequently, participants desire to minimize the cost of their activity.

A fraction θ of the payments each participant must make are assumed to be time-sensitive or 'urgent.' The remaining share of payments are assumed to be non-time-sensitive or 'trivial.' The cost of making urgent payments off-network is $\bar{\varphi}$. The off-network cost of trivial payments is $\varphi < \bar{\varphi}$. We also assume participants must pay costs φ and $\bar{\varphi}$ to receive trivial and urgent payments, respectively, off-network.

---

[6] For pedagogical reasons, it may be useful to imagine the participants arranged around a circle of unit perimeter. However, this geometry plays no role in our model.

[7] For example, participants may be local monopoly providers of banking services. As local monopoly providers, participants' retail pricing decisions would be determined by relative demand for products rather than the relative cost of producing these various services. Consequently, we assume that the price charged to clients is independent of whether payments are ultimately sent or received on- or off-network. Although the price charged could depend on whether payments are urgent or trivial, analysis of optimal pricing at the retail level would be disjoint from the investment problem that is the focus of this analysis.

The cost of making and receiving payments on-network does not depend upon whether the payment is urgent or trivial. Participants must pay $p^s + \delta$ for each payment sent and $p^r + \delta$ for each payment received over the network. δ may be thought of as the participant resource cost of 'hooking up' to the network whereas p^s and p^r are usage fees set by the network owner. The marginal cost of network usage to the network owner is zero.[8]

The magnitude of the hook-up cost depends on whether an investment has been made in a network-specific technology. If no investment has been made, we assume $\delta = \bar{\delta}$ where $\varphi < \bar{\delta} < \bar{\varphi}$. If participants choose to invest in the technology, they pay γ and reduce the cost of hooking up to zero. Hence, participants who have paid γ must pay only p^s for payments sent and p^r for payments received. Table 2 provides a summary of costs incurred for sending and receiving payments.

Table 2: Cost of Payments

	Trivial $(1-\theta)$	Urgent (θ)
Off-network	φ	$\bar{\varphi}$
On-network w/out investment	$p^{s,r} + \bar{\delta}$	$p^{s,r} + \bar{\delta}$
On-network w/investment	$p^{s,r}$	$p^{s,r}$

To fix ideas, consider a particular analog in which inter-bank payments can be either transferred over an electronic network or in the form of a check through the mail. Sending and receiving payments by mail would result in the relatively low administrative cost of maintaining a mail room. Because the mail is slow, urgent payments transferred off-network would require a premium, perhaps for the cost of an armored courier. Since on-network payments are relatively fast and secure, there is no difference in cost between urgent and

---

[8] The fact that there is a cost for both receiving and making payments is common in the literature on two-sided markets (see, for example, Rochet and Tirole 2004). It is implicitly assumed that the Coase theorem does not hold, either because of private information, or transactions cost and regulatory constrains, or both.

trivial payments. The costs incurred when payments are transferred in this way correspond to both the network usage fees and the expense of ensuring the accuracy of each transaction. Alternatively, banks could invest in computer systems to automate coordination and verification of accurate funds transfers across accounts. In this case, on-network costs would be limited to the fees paid for network usage.

2.1 The planner's problem

To establish a benchmark allocation, consider the problem for a planner who must decide whether to invest in the technology. We assume the planner cares only about payments being made and thus wants to minimize the total cost of this activity. As assumed above, the marginal cost of network usage is zero. The cost of the technology is γ per participant. Hence the total cost for the mass 1 of participants is γ. The benefit from investing in the technology is that all payments issued and received on-network have no cost.

The cost if the planner invests is

$$C^i = \gamma. \tag{1}$$

If the planner does not invest, the cost is

$$C^o = 2[\theta\bar{\delta} + (1-\theta)\varphi] \tag{2}$$

as the mass 1 of agents send and receive their urgent share (θ) of payments on-network at hook-up cost ($\bar{\delta}$) while they send and receive their trivial share $(1-\theta)$ of payments off-network at the relevant cost (φ). Investment is chosen whenever $C^i \leq C^o$. The following proposition summarizes this result.

Proposition 1 *A planner will invest in the technology whenever* $\gamma \leq 2[\theta\bar{\delta} + (1-\theta)\varphi]$.

3 The commitment case

In this section we consider a network able to commit to prices for network usage. Contingent on these prices, participants choose whether or not to invest in the network-specific technology. Finally, participants choose their mix of on- and off-network payments.

Given the ability to commit to usage fees, the network owner always prefers to set a low marginal price for sending and receiving payments. A fixed fee can then be used to extract resources from the network participants in a lump sum fashion.[9] Consequently, we can begin the analysis by assuming marginal prices $p^s = p^r = 0$. With such prices, participants who have not invested in the technology choose to send their urgent payments on-network and their trivial payments off-network. Participants who have invested in the technology send all payments on-network.

The remainder of the section shows that multiple equilibria can arise because of a network effect. Indeed, participants will invest in the network-specific technology if sufficiently many other participants do and will not if sufficiently few do. This multiplicity implies value to giving participants the incentive to invest in the technology regardless of other participants' investment decisions.

3.1 Decentralized investment

Let λ denote the fraction of participants that invest in the technology. The profits for a cost-minimizing network participant are π^o if the participant does not invest and π^i if it does. These profits depend on whether or not other

---

[9] Such a fee can be thought of as a reduction of R.

participants have invested in the technology.

$$\begin{aligned} \pi^o &= R - (\theta\bar{\delta} + (1-\theta)\varphi) - \lambda\bar{\delta} - (1-\lambda)(\theta\bar{\delta} + (1-\theta)\varphi), && (3) \\ \pi^i &= R - \gamma - (1-\lambda)(1-\theta)\varphi. && (4) \end{aligned}$$

Since $\bar{\delta} < \bar{\varphi}$, every participant chooses to send urgent payments on-network. Since $\varphi < \bar{\delta}$, participants who have not invested in the technology send trivial payments off-network.

Equation (3) indicates participants who have not made the investment pay $\bar{\delta}$ for the urgent share θ of payments they make on-network and φ for the trivial share of payments they make off-network. All payments received from the fraction λ of participants who have made the investment come on-network at a price $\bar{\delta}$. The cost of payments received from participants who have not made the investment depends upon their urgency. The urgent share of these payments are received on-network at price $\bar{\delta}$ while the remainder are received off-network at price φ.

Equation (4) is interpreted similarly. Since the investment has been made, all payments sent go on-network at no charge. All payments received through the network also come at no charge. However, trivial payments (fraction $1-\theta$) received from participants who have not made the investment (fraction $1-\lambda$) result in off-network charges (price φ).

Participants choose to invest in the technology if $\pi^i \geq \pi^o$, which is true if and only if

$$\gamma \leq 2\theta\bar{\delta} + (1-\theta)(\varphi + \lambda\bar{\delta}). \tag{5}$$

By investing in the technology, participants incur a cost γ. On the other hand, they save $\bar{\delta}$ on the urgent share of payments θ both sent and received on-network. In addition, they save φ on the trivial share of payments $(1-\theta)$ sent off-network. Finally, they save $\bar{\delta}$ on the trivial share of payments received on-network from other investing participants (fraction λ). The only marginal cost a participant cannot avoid by investing is φ paid for off-network receipts of trivial payments from non-investing participants.

Clearly, if $\gamma \leq 2\theta\bar{\delta}+(1-\theta)\varphi$ then participants will invest in the technology regardless of what other participants do. Similarly, if $\gamma \geq 2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta})$ participants will not invest regardless of what others do. Parameters in these ranges yield unique equilibria. However, if

$$2\theta\bar{\delta}+(1-\theta)\varphi \leq \gamma \leq 2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta}) \tag{6}$$

then there are multiple equilibria corresponding to λ values of 0, 1, and λ', where λ' solves $\gamma = 2\theta\bar{\delta}+(1-\theta)(\varphi+\lambda'\bar{\delta})$.

We can define a notion of stability of these equilibria with respect to small deviations of network participants' beliefs about λ. We say that an equilibrium λ is unstable if an arbitrarily small deviation from the beliefs necessary to sustain this equilibrium gives rise to a different equilibrium. Let $\eta \in [0,1]$ denote the probability with which a participant invests in the technology if that agent believes that a mass λ_η of participants invest in the technology.

Definition 1 *An equilibrium λ is unstable if, $\forall\varepsilon > 0$, $|\lambda_\eta - \lambda| > \varepsilon \Rightarrow \eta \neq \lambda$.*

It is obvious that λ' is not stable. If $\gamma \geq 2\theta\bar{\delta}+(1-\theta)\varphi$ a low-investment equilibrium is stable. Alternatively, if $\gamma \leq 2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta})$ a high-investment equilibrium is also stable. Hence, for all values of γ between these two bounds, both the low-investment and the high-investment equilibrium are stable.

3.2 Coordinated investment

In this section, we show an opportunity for coordination exists. Multiple equilibria arise with decentralized investment because participants must pay a fixed cost up front, while the benefits that they obtain from the technology will depend on other participants' behavior. Instead, if it is possible to pay, at least partly, for the technology as a variable cost depending on usage, then we can show that the equilibrium with high investment will be unique.

We assume the existence of a 'coordinator,' either a third party or an entity working for the network owners.[10] The coordinator can invest in the technology on behalf of network participants and charge them some variable cost. The coordinator is assumed to face a production function with constant returns to scale; i.e., it must pay a cost γ for each participant. By doing this, we focus on the highest-cost case for the coordinator. Below we discuss the case where the investment represents a cost-reducing innovation in network usage. In such an event where investments are duplicative, complete property rights allow the innovator to obtain non-negative profits by implementing the high-investment equilibrium.

After the network owner has announced prices p^s and p^r, the coordinator announces prices it charges network participants on behalf of whom it has invested in the technology. These prices are q^s per payment sent, q^r per

---

[10] It is possible to endogenize the role of the coordinator by assuming that several potential coordinators compete for the market. In the case of a CRS technology, as is studied in this section, this amounts to assuming potential coordinators are endowed with different aptitudes for developing the organizational and contracting technology needed for coordination. If we assume that the realization of firm-specific innovative capabilities is common knowledge, the coordination game would be preceded by a preliminary winner-take-all stage and only the most capable coordinator would enter the market for this service. In the case of an IRS technology, which is discussed in section 3.4, the most efficient coordinator would underprice others. Such a result would obtain if potential innovators are defined as in Klepper (1996), who emphasizes differences in firm-specific innovative capabilities. Alternatively, the network owner can be assumed to provide coordinating services.

payment received, and a fixed fee f.[11] Subsequently, network participants choose how to send their payments.

Let λ^c denote the fraction of network participants that have invested through the coordinator. Assuming variable prices are sufficiently low to ensure participants will prefer to send and receive all payments over the network, a break-even fixed fee is identified for the coordination service provider. These prices are then shown to provide incentives for participants to access the technology via the coordinator. Finally, these prices are shown to be feasible when parameters fall in the range of multiple equilibria identified in condition (6).

The coordination service provider's profits derived from this price scheme are defined as

$$\pi^{CSP} = -\lambda^c \gamma + \lambda^c f + \lambda^c q^s + \lambda^c [\lambda q^r + (1 - \lambda)\theta q^r] \tag{7}$$

where $\lambda \geq \lambda^c$ is the total share of participants with access to the network-specific technology through either the coordinator or their own investment. The coordinator incurs cost of investment (γ) and revenues in proportion to the share of participants installing the technology via the coordinator. Every network-participating client pays the fixed fee f. Assuming $q^s \leq \varphi$, client participants will prefer to send even trivial payments over the network. Assuming $q^r \leq \bar{\delta}$ assures client-participants will prefer to receive on-network payments through the network-specific technology.[12] The coordinator receives q^r for payments received by clients from all users of the technology who make all payments on-network. Finally, the coordinator also receives q^r from clients

---

[11] We do not restrict q^s, q^r or f to be strictly positive.

[12] If the coordinator can costlessly monitor network participants in order to prevent them from unhooking the technology, then it is possible to charge q^r high enough such that the fixed fee f can be set equal to zero. However, if $q^r > \bar{\delta}$ and monitoring is costly, participants may have an incentive to 'unhook' the technology when they are not sending payments and save $q^r - \bar{\delta}$ on payments received.

for urgent payments received from non-users of the technology. If a high-investment equilibrium exists, the break-even condition for the coordinator whenever $\lambda = 1$ is

$$f = \gamma - q^s - q^r. \tag{8}$$

If π^c are the profits of a participant with access to the cost-reducing technology by way of the coordinator, then

$$\pi^c = R - f - q^s - \lambda q^r - (1 - \lambda)(\theta q^r + (1 - \theta)\varphi). \tag{9}$$

Participants will choose the technology through the coordinator if $\pi^c \geq \pi^o$, which is true if and only if

$$f + q^s + \lambda q^r + (1 - \lambda)\theta q^r \leq 2\theta\bar{\delta} + (1 - \theta)(\varphi + \lambda\bar{\delta}). \tag{10}$$

If the coordinator chooses $q^s = \varphi$ and $q^r = \bar{\delta}$, then participants will choose the technology through the coordinator if and only if

$$f \leq \theta(\bar{\delta} - \varphi). \tag{11}$$

The total cost of the technology to participants is then

$$f + q^s + q^r \leq (1 + \theta)\bar{\delta} + (1 - \theta)\varphi. \tag{12}$$

Participants will adopt the technology through the coordinator rather than through their own investment if $\pi^c \geq \pi^i$, which is true if and only if

$$f + q^s + \lambda q^r + (1 - \lambda)\theta q^r \leq \gamma. \tag{13}$$

Given $q^s = \varphi$ and $q^r = \bar{\delta}$, $\pi^c \geq \pi^i$ provides incentives for all participants to choose the coordinator over own investment and $\lambda = 1$ if and only if

$$f \leq \gamma - \varphi - \bar{\delta}. \tag{14}$$

That is, $f + q^s + q^r \leq \gamma$ assures prices are incentive compatible for all participants to obtain the technology through the coordinator rather than through own investment. Rearranging the right hand side of (12) to $2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta})$, it is obvious that if parameters are in the range of multiple equilibria specified by condition (6), then the total cost to participants when prices are chosen to assure $\pi^c \geq \pi^i$ is less than the total cost when prices are chosen to assure $\pi^c \geq \pi^o$. And these prices satisfy the coordinator break-even condition specified in equation (8).

We summarize these results in the following proposition.

Proposition 2 *If* $\gamma \leq 2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta})$, *then the coordinator can implement the equilibrium with investment uniquely.*

3.3 Comparison to the planner's allocation

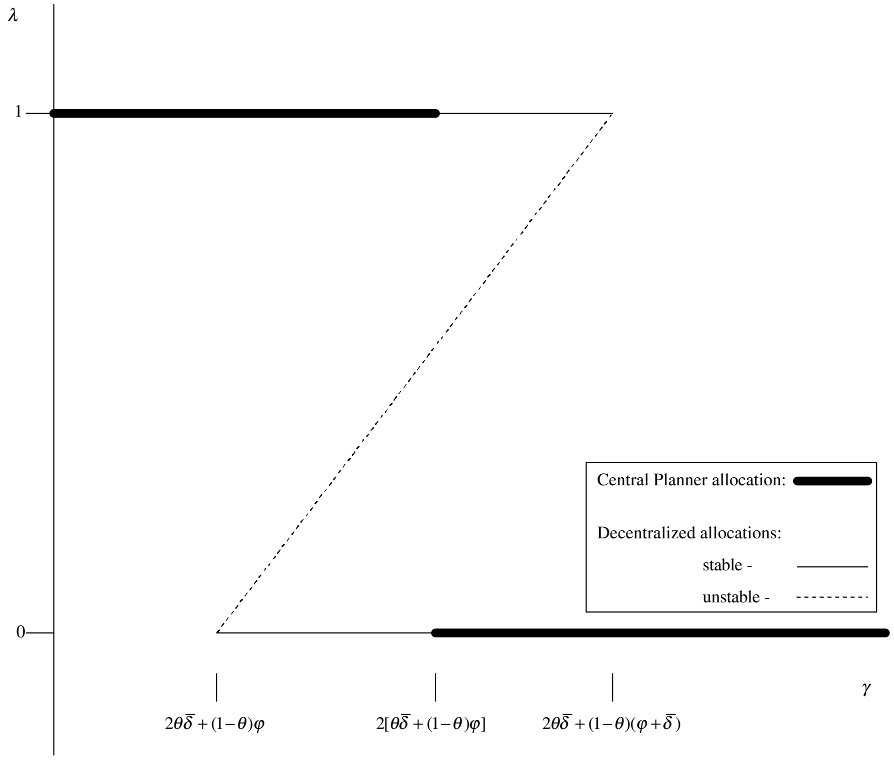
Contrasting the participant investment rules with network pricing commitment to that of the central planner presented in Proposition 1 yields Proposition 3.

Proposition 3 *There can be too little investment as well as too much investment in this economy.*

Proof. Suppose $2\theta\bar{\delta}+(1-\theta)\varphi \leq \gamma < 2[\theta\bar{\delta}+(1-\theta)\varphi]$. Then the planner would choose to invest in the technology but the decentralized equilibrium with no investment could occur. In this case, investment would be below the social optimum. Conversely, suppose $2[\theta\bar{\delta}+(1-\theta)\varphi] < \gamma \leq 2\theta\bar{\delta}+(1-\theta)(\varphi+\bar{\delta})$. Then the planner would choose not to invest in the technology but the decentralized, high-investment equilibrium could occur. In this case, investment would be above the social optimum. ■

Figure 1 illustrates the correspondence between the decentralized λ equilibria and the central planner's allocation in the γ parameter space. The remainder of the analysis disregards the unstable equilibria. Instead we focus exclusively on the two equilibria where either all participants invest or no participant invests.

Figure 1: Decentralized Equilibrium Investment Shares



The deviation of the private from the social allocation results from an externality associated with charges for receipts. Under decentralized decision making, potential investors do not consider the costs imposed on payment recipients. Consequently, if γ is sufficiently large but participants expect others to invest in the technology there can be too much investment. In this case, it can be individually rational for a participant to invest even if it would have been socially optimal for all participants not to invest. Conversely, too little investment occurs if γ is sufficiently small but participants expect others not to invest in the technology. In this case, it can be individually rational for a participant not to invest even though it would be socially optimal for all participants to do so. The central planner solves this collective action problem by considering only the extreme cases where all participants invest or no participants invest.[13]

As $\varphi \to 0$, the range of parameters for which there can be underinvestment shrinks to a single point. Since payments off-network are nearly costless, there is little scope for the central planner to save costs by coordinating investors to make payments on-network. In this case, the main concern is that the high-investment equilibrium might occur. As $\varphi \to \bar{\delta}$, the range of parameters for which there can be overinvestment shrinks to a single point. Since the cost of sending payments off-network is almost as high as sending them on network, there is little scope for the central planner to save costs by coordinating in-

---

[13] The collective action problem becomes obvious if we consider the special case where the fraction of urgent payments becomes vanishingly small; i.e. $\theta \to 0$. Assuming the cost of investment is smaller than the cost of trivial off-network payments, i.e. $\gamma < \varphi$, the marginal participant would certainly invest. This action would be justified on charges for initiated payments, regardless of the mode of receipts that result from other participant investment decisions. If $\varphi < \gamma < 2\varphi$, the central planner would prefer all participants to invest since the total cost of doing so is less than the total cost of sending all now trivial payments off network. However, the marginal participant may prefer not to invest if he believed he would incur charges for off-network receipts from non-investing participants. Similarly, if $2\varphi < \gamma < \varphi + \bar{\delta}$, the central planner would prefer no participants invest since the total cost of doing so is greater than the total cost of sending all now trivial payments off network. However, the marginal participant may prefer to invest if he believed he would incur charges for on-network receipts from investing participants.

vestors to keep payments off-network. In this case, the main concern is that the low-investment equilibrium occurs.

It follows directly from propositions 2 and 3 that if $2[\theta\bar{\delta} + (1-\theta)\varphi] < \gamma \leq 2\theta\bar{\delta} + (1-\theta)(\varphi + \bar{\delta})$ then a coordinator can implement the equilibrium with investment while the planner would choose not to. The incentive for the coordinator to do so will depend on whether it is independent of the participants or is owned by them.

In the latter case, investment will not be undertaken by the coordinator whenever $\gamma > 2[\theta\bar{\delta} + (1-\theta)\varphi]$. Indeed, in that case the cost of investing in the technology is greater than the amount saved by using the technology. Realizing this, participants will prevent the coordinator from operating. This should be unsurprising since, when the participants control the coordinator, their objective function becomes the same as that of the planner. Of course, in principle this does not eliminate the possibility that the high investment equilibrium might arise nonetheless through uncoordinated individual decisions. However introspection suggests it would be surprising if, after participants jointly decide to prevent the coordinator from implementing the high-investment equilibrium, they would each believe other network participants would independently invest in the technology.

If the coordinator is independent of the participants, these owners cannot simply prevent the coordinator from operating.[14] Indeed, since coordinator revenue is limited to on-network payments, an independent operator prefers to set prices to drive all payment activity on network regardless of the value of γ. It is thus interesting to ask if it might be possible to constrain the coordinator's activity when the high-investment equilibrium is not socially efficient. A set of constraints that assures the coordinator cannot raise revenue in excess of

---

[14] The coordinator always makes zero profits since we have assumed constant returns to scale in the investment technology. Hence, strictly speaking, the coordinator is indifferent between investing or not. However, as will be discussed below, if there is any cost saving to coordinated investment, the coordinator has a strict preference for investing.

$2[\theta\bar{\delta} + (1-\theta)\varphi]$ is sufficient to prevent the coordinator from operating when the high-investment equilibrium is sub-optimal.

To illustrate this point, let us assume the coordinator is allowed to choose q^s and q^r freely, but that a constraint can be imposed on any fixed cost. The coordinator can charge at most $q^s = \varphi$ if participants are to send their payments over the network. If participants are allowed to 'unhook' the technology, the coordinator can charge no more than $q^r = \bar{\delta}$ for payments received. Let $\tilde{f}$ denote the maximum fixed price that may be charged in order to implement only socially efficient high-investment equilibria. In this case

$$\tilde{f} + \varphi + \bar{\delta} \leq 2[\theta\bar{\delta} + (1-\theta)\varphi] \tag{15}$$

which implies

$$\tilde{f} \leq (2\theta - 1)[\bar{\delta} - \varphi]. \tag{16}$$

Restricting the final allocation to be socially efficient requires a limit on the fixed price proportional to the spread between the hook-up cost and the cost of trivial off-network payments. When $\theta \geq 0.5$, the coordinator should not be allowed to charge a fixed price greater than this bound. In this case, there are relatively many urgent payments to be made and the fixed-price limit is increasing in hook-up cost and the cost of trivial off-network payments. When $\theta < 0.5$, the coordinator should be prohibited from charging a fixed price and should be charged a fixed tax per participant equal to the absolute value of the bound. In this case, there are relatively few urgent payments to be made and the fixed tax is increasing in hook-up cost and decreasing in the cost of trivial off-network payments. The proceeds from the tax can be returned to participants. These constraints guarantee the coordinator will not operate in the region of the parameter space where the high-investment equilibrium is suboptimal.

3.4 Discussion: cost duplication and property rights

The previous sections have shown that a multiplicity of equilibria in the participant investment decision creates a valuable opportunity for coordination. The analysis focused on a coordinating agent investing in a constant-returns-to-scale network-specific technology. Our objective here has been to show that even absent true cost savings to coordinating investment, doing so is sufficient to overcome the network problem demonstrated in Section (3.1). A more realistic assumption may be that at least some costs incurred through decentralized investment in the network-specific technology are duplicative. In such an event, positive profits will accrue to the coordinator that may be used to offset contracting and enforcement costs.

For example, consider a case in which the investment represents a potential innovation in the participant cost of hooking up to the network. Assuming zero marginal cost of duplication of the innovation, decentralized investors face two opportunities: one to overcome the coordination problem specified above, a second to avoid duplicative innovation. Absent the ability to appropriate gains associated with application of the innovation, participants may be unable to justify expenditure on the innovative activity on the basis of their own small share of the total payments market. A system of patents could be introduced, however, to award property rights to application of the innovation. The single innovator would then license the network-specific technology to participants. Positive profits attributable to avoiding duplicative expenditure on the innovation could then be used to offset the cost of monitoring and enforcing the property rights.

To conclude this section, we note that a network effect does not appear to pose a significant barrier to innovation when network access is priced at marginal cost. A coordinator is able to implement the high-investment equilibrium from the multiplicity attributable to the network effect. Indeed, the main concern seems to be how to prevent overinvestment from occurring. As we will see below, it is the ability of the network owner to commit to prices that allow the high-investment equilibrium to be implemented.

4 The no-commitment case

This section considers the case where the network operator is unable to commit to prices. Instead, the network chooses prices p^s for payments sent and p^r for payments received on-network $after$ network participants have made their investment decisions. Due to this inability to commit, the equilibrium with high investment generally does not exist, even when coordination is possible.

In contrast to the previous section, this result reflects a hold-up problem that cannot be as easily resolved as was the network effect.[15] Once the investment in the technology has been made, the fixed cost is sunk and the network owner will charge participants as much as possible.[16] Anticipating this, participants will prefer not to invest in the technology because they know they will be unable to recover the fixed cost of the investment. When the network owner cannot commit to prices, the only case in which the high-investment equilibrium can be implemented is where it is possible for the investment coordinator to warranty participants from all fixed costs associated with usage of the network specific technology.

Even if only variable costs can be charged, the network operator may prevent the high-investment equilibrium if demand for network payments is suf-

---

[15] Grout (1984), Hart (1995), among others, have shown that specific investment will not be undertaken at the optimal level if contracts are incomplete.

[16] This result assumes it is not possible for the coordinator to charge only a variable cost. For example, a participant that is not paying fixed fees to a coordinator will still incur one-time costs of setting up and learning a new system.

ficiently inelastic. In this case, monopoly profits from a high margin on the low volume of urgent payments dominate profits from a low margin on the high volume of both urgent and trivial payments. This effect is not directly related to the hold-up problem described above but is instead the standard inefficiency associated with monopoly pricing.

4.1 Decentralized investment

Consider the case of decentralized investment in a technology specific to a network. Recall from equation (6) that multiple equilibria exist in the event that γ falls in the range $2\theta\bar{\delta} + (1-\theta)\varphi \leq \gamma \leq 2\theta\bar{\delta} + (1-\theta)(\varphi + \bar{\delta})$. In this case, we prove the following proposition

Proposition 4 *If the network cannot commit to usage fees and investment is decentralized, the high-investment equilibrium does not exist.*

Proof. To establish a contradiction, assume the high-investment equilibrium does exist so that participants have sunk investment γ. The network operator can set $p^s = 0$ and $p^r > 0$. Participants will send all payments on-network since their only alternative to doing so would result in a marginal cost of $\varphi > p^s = 0$. If the network operator sets $p^r > R$, participants make negative profits and choose to exit the market. However, since the cost of investing in the technology is sunk, the network operator can set $p^r = R$. Participants anticipate the optimal monopoly price of $p^r = R$ and therefore expect to make profits of $-\gamma < 0$ following their investment in the network-specific technology. Consequently, participants prefer not to invest. ■

In the previous section, when investment in the technology was done through the coordinator, we had to take into account the fact that participants may have the ability to 'unplug' the technology when receiving payments. In this section this is not an issue since the price p^r is charged for usage of the network and not usage of the technology. Implicitly, we assume not accepting payments through the network is equivalent to exiting the market.

4.2 Coordinated investment

Assume it is not possible for participants to incur only a variable cost for use of the technology. For example, there may be a fixed cost required of the participants to learn the technology as discussed in footnote 16. Or, as discussed in footnote 12, perhaps high variable prices would leave participants with an ex-post incentive to unplug the technology to avoid paying the technology usage fee for on-network receipts. We show that in this case the equilibrium with high investment only exists when network participants receive a subsidy for fixed costs associated with use of the network-specific technology. And even in this case, the network operator may prevent the high-investment equilibrium if demand for network transmission is sufficiently inelastic.

Assume, without loss of generality, that an independent coordinator charges participants a fixed cost $f \in (0, \gamma]$ as well as variable costs $q^s \geq 0$ and $q^r \geq 0$ high enough to recover its total costs.

Proposition 5 *When the coordinator charges some fixed cost and participants do not control the network operator then only the no-investment equilibrium exists.*

Proof. By way of contradiction, suppose that all participants acquire the technology through a coordinator. If the network operator chooses $p^s = 0$, it can charge each participant up to $p^r = R - q^r - q^s$. At that price, participants make no margin on their payment activity. If the network operator were to charge more, participants would make a negative margin on payments and would choose to exit the market. Since they make no margin, participants are unable to recover the fixed cost, f, which is sunk. Since they anticipate such monopoly pricing behavior, participants prefer not to invest in the technology. ■

The proof of proposition 5 does not go through whenever a credible claim can be made to subsidize all participant fixed costs. Indeed, since there are no fixed costs to cover in this case, participants are willing to invest in the technology as long as they make at least zero profit.[17]

Proposition 6 *When participants do not control the network operator, the full-investment equilibrium exists if participants can avoid all fixed costs.*

Proof. By way of contradiction, assume participants have not acquired the technology. Assuming $p^s = 0$ and p^r unrestricted, the network operator can charge $p^r \leq R - q^s - q^r$. Hence the high-investment equilibrium exists and is unique. ■

4.2.1 Monopoly pricing for network usage when the price for payments received is limited and demand is sufficiently inelastic

Proposition 6 shows that the high-investment equilibrium exists if use of the technology requires only variable costs. For example, a monopolist network owner may be able to coordinate investment and provide a subsidy to participants to defray fixed costs of technology adoption. Even in this case, however, we show that if the network owner is limited in how much it can charge on pay-

---

[17] The precise way in which fixed-cost subsidization could be achieved is beyond the scope of this analysis. However, realistic assumptions in this regard suggest it may be difficult to avoid hold-up, even if full-investment obtains in the present formalization. For example, the network owner could provide the fixed-cost subsidy. However, if fixed costs varied across participants, all participants would have an incentive to misrepresent themselves as a high-cost type. Alternatively, the coordinator could provide the subsidy. However, this would simply shift the hold-up to the coordinator-participant relationship if the coordinator could not commit to variable fees q^s and q^r.

ments received,[18] there are parameter values for which only the no-investment equilibrium exists. Specifically, this result depends on the elasticity of demand for network access.

Proposition 7 *Assume the monopoly must set* $p^r = \bar{p}$*. If* $\theta\bar{\varphi} > \varphi$ *and if* $\bar{p}$ *is sufficiently small the high-investment equilibrium cannot be implemented in the region of the parameter space where multiple equilibria occur.*

Proof. By way of contradiction, assume without loss of generality that the coordinator charges $q^r > 0$ and $q^s = 0$. Also assume all participants have invested in the technology through the coordinator. Let $\bar{p} = 0$. Whether participants make all their payments or only urgent payments over the network depends on the price p^s chosen by the monopoly. If $p^s \leq \varphi$, then all payments are made over the network. The monopoly's profit is maximized and equal to φ when $p^s = \varphi$. If $\varphi < p^s \leq \bar{\varphi}$, then only urgent payments are made over the network. In that case, the monopoly's profit is maximized and equal to $\theta\bar{\varphi}$ when $p^s = \bar{\varphi}$. If the monopoly chooses $p^s > \bar{\varphi}$, no payment is made on the network and the monopoly makes zero profits.

If $\theta\bar{\varphi} \geq \varphi$, it is optimal for the monopoly to charge a price so high that only urgent payments are sent through the network. Since such payments are made through the network anyway, a coordinator cannot improve upon decentralized investment. Participants choose to invest in the technology only if $\gamma \leq 2\theta\bar{\delta}$, which is outside of the region in which multiple equilibria occur.

By continuity, the proof continues to hold for small values of $\bar{p} > 0$. ■

---

[18] This case is particularly interesting in light of policy debates over whether it is 'fair' to be charged for transactions one did not initiate. For example, interchange fees may be interpreted as the price charged merchant (participants) by the credit card (network) to receive payment from a card holder (participant.) The proof to proposition 7 shows that if demand for on-network payments is sufficiently inelastic then limiting the price for payments received can avoid investment in the network-specific technology, even when such investment would be socially optimal.

The intuition for this result is that the monopolist network owner may earn higher profits by charging a high price for urgent payments alone than by charging a lower price on all payments. This depends on the elasticity of demand for network access. In our simple model, the demand curve only has two points: either all payments go through the network or only urgent payments do. The demand curve is relatively inelastic if the difference between the price at which all payments are made through the network and the price at which only urgent payments are made through the network is relatively large. Hence, if the demand curve is sufficiently inelastic, the monopolist prefers to set a high price and restrict quantity.

Figure 2: Demand for Sending Payments On-network, $p^r = q^s = 0$

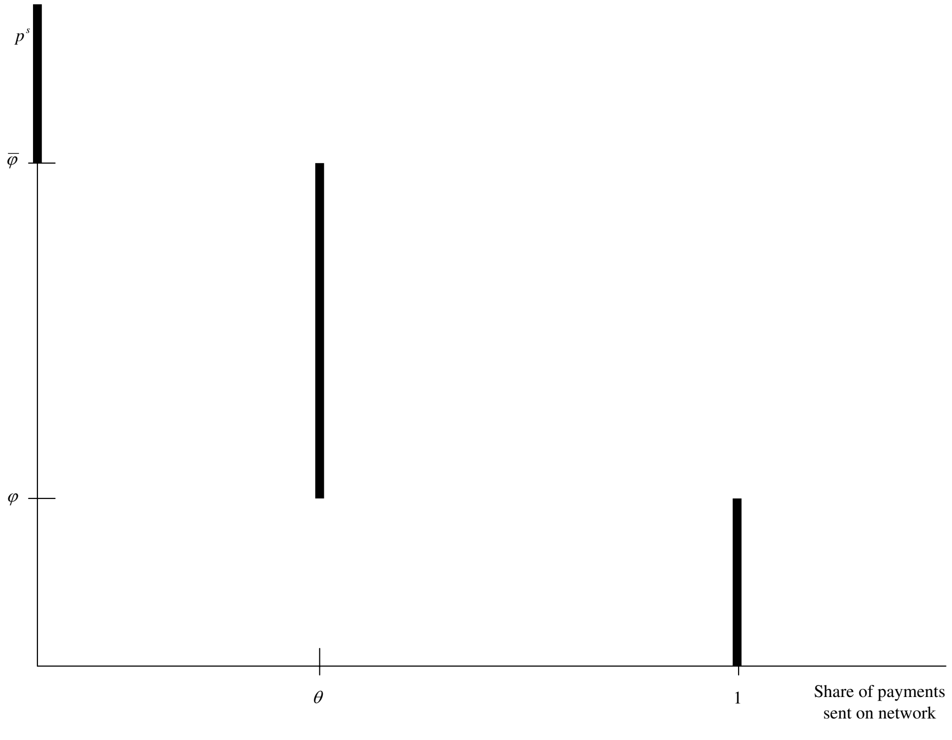


Figure 2 illustrates this point for the particular set of prices considered in the proof. In this case, the elasticity of demand for sending payments over the network is $(\frac{1-\theta}{1+\theta})(\frac{\varphi+\bar{\varphi}}{\varphi-\bar{\varphi}})$. The demand curve is inelastic if this expression is smaller than -1. This is the case if $\theta\bar{\varphi} > \varphi$, which is true if and only if $\theta(\bar{\varphi}-\varphi) > (1-\theta)\varphi$. That is, the optimal monopoly price will restrict network usage if the premium that can be charged on urgent payments exceeds the total revenue foregone on trivial payments. Thus, intuition derived from this stylized model extends to more realistic cases where the demand curve is not restricted to be two points.

4.3 Comparison with the planner's allocation

Proposition 4 states that for all values of $\gamma > 0$, the decentralized high-investment equilibrium cannot occur. Hence, if $0 < \gamma \leq 2[\theta\bar{\delta} + (1-\theta)\varphi]$ the equilibrium allocation is suboptimal. Moreover, note that the high-investment allocation cannot occur even when it would be individually rational for participants to invest regardless of beliefs about other participants, i.e. when $0 < \gamma < 2\theta\bar{\delta} + (1-\theta)\varphi$. Recall with commitment, the high-investment equilibrium is unique for these parameter values.

More interestingly in absence of commitment, opportunities for coordination are limited because coordination alone cannot solve the underinvestment problem. In this case, proposition 5 shows that any measure of fixed costs will avoid the high-investment equilibrium, even for parameter values for which the planner would choose to invest.

If it is possible for the coordinator to charge only a variable cost then the socially optimal level of investment will be implemented if the demand curve is sufficiently elastic. If $\gamma < 2[\theta\delta + (1-\theta)\varphi]$ then the coordinator will implement the high-investment equilibrium which is optimal. If $\gamma > 2[\theta\bar{\delta} + (1-\theta)\varphi]$ then the monopoly network owner will avoid high investment, even if the coordinator would prefer it. In this case, the network owner could price payments sent sufficiently high to drive trivial payments off network. The monopolist network owner would thereby maximize the value it can extract through the 'receiver pays' feature of this two-sided market.

If the price p^r that can be charged is restricted, then the monopolist might choose not to subsidize the fixed cost of the technology. If this is the case, there will be underinvestment whenever $\gamma < 2[\theta\delta + (1-\theta)\varphi]$.

This problem illustrates an interesting feature of this two-sided market. If p^r is unrestricted, the monopolist does not create the usual inefficiency of one-sided markets by charging a high price p^s. Since participants cannot affect the cost of payments received, the monopolist can implement the efficient allocation even while it maximizes its own surplus. Hence, an interesting policy implication from Proposition 7 is that the network owners should be allowed to charge for payments received. The charge for payments made through the network should be kept to a minimum.[19]

5 Discussion

This paper suggests inability to commit to prices for network usage can lead to inefficiently low investment in network-specific technologies. Mechanisms that can achieve commitment therefore present a profitable opportunity. Consequently, we expect networks will adopt governance structures that mitigate this commitment problem. Moreover, these governance arrangements will also be sufficient to solve the problem arising from the network effect.

Several cases from the payments industry are illustrative. The payments function of revolving-credit and charge card programs is a system of accounts that allows merchant and consumer patrons to exchange goods and services without carrying cash. Absent a cost-effective retail interface (e.g. the swipe

---

[19] If there were congestions costs on the network, the charge for payments sent would be strictly positive. However, that would not change the logic of the argument that they should be kept to a minimum compatible with preventing excess usage of the network. Note, for example, that on payment systems such as Fedwire and FedACH a fee is charged to recipients as well as to senders. For Fedwire, the amount of the fee is the same for both. For FedACH, the fee per item can be greater for the recipient that for the originator.

card, expenditure reports valued by consumers and merchants, consumer promotions valued by merchants,) use of the system would be relatively costly for patrons. Banks acquiring merchants and/or issuing cards to consumers would have some incentive to invest in development of such a cost-effective retail interface. However, as suggested by the model, a network effect may avoid investment – the incentive to invest in such an innovation would depend on the investment decisions of other acquiring and/or issuing banks. Also as suggested by the model, if the network effect were the only cause of sub-optimal investment, an independent coordinator could invest on behalf of merchant-acquiring and card-issuing banks in order to implement the high-investment equilibrium. Without commitment, however, even a coordinator cannot prevent such investment being held up.

Indeed, the historical evidence suggest these factors were in play during the earliest stages of VISA. The brand was created in 1970 when Bank of America decided to transfer ownership of the Bank Americard program to licensed issuers of the card. Apart from the joint ownership of VISA's assets, a key aspect of this organizational structure is that it called for centralization of functions that benefited all members jointly.[20] From the perspective of our model, what is most interesting is the consolidation of research and development (R&D) -type expenditures. This can be interpreted as an effort to overcome the network effect by introducing a *network-owned* coordinator in charge of making investments on behalf of participants. If the network effect had been the main barrier to innovation, centralizing R&D should have been enough and there would be no obvious reason for Bank of America to transfer ownership of the network to its participants. Indeed, given the value of VISA

---

[20] Chutkow (2001.) Also, Evans and Schmalensee (2005, p. 6) observe that payments associations of financial institutions allow cooperation in efficiency-generating areas such as "design and operation of the vast computer networks that now enable transactions around the world to be completed in just a few seconds, as well as advertising an some aspects of product development."

today, this could have been a major mistake.

Taking into account the hold-up problem brought about by the lack of commitment suggests instead that joint ownership of network assets was key to the development of VISA. Consider a hypothetical institution that would have been a participant of the network but not a joint owner. Such an institution would realize that the benefits from any network-specific investment it made could be extracted by the network. This would reduce incentives to invest.

To promote innovation, the network owner would have to find a way to credibly commit not to expropriate the benefits from investment. One way to achieve this would be for the network to be jointly owned by potentially-innovating participants. Hence, National Bank Americard Incorporated, jointly owned by card-issuing banks, is an illustration of a governance structure that emerges for its superior capability to achieve commitment.

The history of MasterCard is also illustrative. MasterCard evolved from a group of east coast banks that were issuing paper that could be used as cash in local stores. In 1951, the Franklin Bank of New York issued the first conventional credit card. Over time, a system of banks emerged that would accept the card as payment with merchants that they had chosen to work with. In 1966, one of these groups formalized their relationship as the Interbank Card Association, which would later become MasterCard International.[21] Unlike the VISA story, MasterCard began as an organization that was jointly owned by card-issuing and merchant-acquiring banks. Consistent with the implications of our model, it is not surprising that VISA would evolve toward an organizational form first established by MasterCard.

The story of Amex suggests integrated ownership is an alternative governance mechanism that can achieve commitment. American Express was formed in 1850 from the merger of Wells and Co. and Butterfield, Wasson and Co., two prominent shipping firms linking the eastern seaboard to Buffalo,

---

[21] MasterCard International. Mandell (1990.)

New York and the growing cities in the midwest.[22] As rail transport replaced stage coach following completion of the Transcontinential Rail Road in 1869, American Express transformed itself from a from a freight shipper to a freight forwarding firm.[23] The firm used its geographically dispersed field offices to diversify into financial and travel services in response to its waning dominance of the freight industry.

In 1952, the earliest days of the charge card industry, American Express had 63 domestic and 209 foreign field offices.[24] Eyeing the popularity of the Diners' Club Card, American Express launched a charge card in 1958. Between the goodwill the company had generated through its financial and travel services operations and a strategic alliance with the American Hotel Association, American Express had over 250,000 cards issued when it finally launched the product.[25] Although it would take a number of years for the card to turn a profit, the American Express card would become one of the company's defining and most profitable ventures. The American Express card weathered early losses without drastic changes to its form of governance. This is consistent with the model insofar as American Express' dispersed network of field offices that promoted the card in its earliest days were integrated under the same governing structure as the card division.

A final application for our model is the case of Fedwire. Fedwire is a system that allows real-time transfer of funds between bank patrons. Biehl, McAndrews, and Stefanadis (2002) document a significant differential between wholesale and retail prices for Fedwire transfers. Specifically, the authors report wholesale prices averaging about 25 cents while retail prices range up to 100 times that amount. A cost accounting of Fedwire retail transactions suggests this large and persistent price differential represents real resource costs.

---

[22] Grossman (1987.)

[23] Reed (1952.)

[24] Ibid.

[25] Grossman (1987) p. 284.

Absent automation of the wire-transfer process, each retail transaction entails a relatively costly process in which several employees must record and verify information necessary to transfer the requested balance across internal accounts and, ultimately, out of the bank. But such a finding begs the question, why don't banks invest in automation of the retail Fedwire transaction? One possibility is a network problem. However, our model suggests that a coordinating agent could implement the high-investment equilibrium where commitment to network usage fees is feasible. Consequently, our model suggests that the key problem is a perceived inability for the Federal Reserve to commit to future prices for Fedwire transactions.

In principle, prices for Fedwire are not determined by a profit-maximizing entity. The Federal Reserve is required to charge only enough to recover its cost. However, investment could be held up if Fedwire users do not believe that the Federal Reserve can credibly commit to cost-recovering prices. For example, 'cost recovery' is not credible absent complete transparency. This may be difficult to achieve where costs are shared and therefore subject to a range of possible allocation schemes. Consequently, the results presented in this paper suggest underutilization of Fedwire assets is a result of hold-up rather than a network effect. This finding may be of interest to policymakers concerned with increasing utilization of Fedwire network assets.

Several solutions to the commitment problem are possible. As has been noted above, it might be possible to encourage innovation by subsidizing any fixed cost associated with such investment. However, the Federal Reserve might not be authorized to do such a thing. An alternative would be for the Federal Reserve to do the innovation itself. While this would solve the problem in principle, it is legitimate to ask whether this kind of R&D activity is best undertaken by the Federal Reserve. Yet another possible solution would be to transfer ownership of Fedwire assets to its users, as in the case of VISA. This solution proved very effective for VISA, but the Federal Reserve might view retaining ownership of Fedwire as important for its ability to fulfill some aspect of its mission. Finally, if lack of transparency is an important factor in the hold up of Fedwire-specific investment, it might be possible to make the way the pricing of Fedwire is determined more transparent. If Fedwire users feel the Federal Reserve can credibly commit not to expropriate the value of their investment, the users or a third-party coordinator would have greater incentives to innovate.

Studies of networks typically focus on network externalities, or the extent to which social gains may be derived from coordinated usage. Though less considered in the literature, investment specificity is also a feature representative of many network environments. This paper presents a model that combines a network effect with a hold-up problem to illustrate the relationship between these phenomena. The analysis suggests that, if a network can commit to usage fees, a number of pricing schemes would allow a coordinator to implement high investment in network-specific technology. If the network is unable to commit, however, the expectation of optimal pricing for network access will hold-up investment associated with any measure of fixed costs.

References

Biehl, Andrew, James McAndrews, and Chris Stefanadis. 2002. "A Review of the Retail and Wholesale Markets for Funds Transfers." Working paper presented at the Federal Reserve Bank of Cleveland, Workshop for Issues Concerning the Federal Reserve and the Payments System, Cleveland, December 11, 2002.

Cardillo, Matthew, Antoine Martin, and Michael J. Orlando. 2004. "Innovation on networks: coordination, governance, and the case of Visa." *Journal of Financial Transformation* 12, 104-106.

Chutkow, Paul. 2001. *VISA: The Power of an Idea.* Chicago: Harcourt.

Evans, David S., and Richard Schmalensee. 2005. *Paying with Plastic: The Digital Revolution in Buying and Borrowing.* Cambridge: MIT Press.

Farrell, Joseph, and Garth Saloner. 1985. "Standardization, compatibility, and innovation." *RAND Journal of Economics*, 16(1), 70-83.

Grossman, Peter Z. 1987. *American Express: The Unofficial History of the People Who Built the Great Financial Empire.* New York: Crown Publishers, Inc.

Grout, P. A. 1984. "Investment and wages in the absence of binding contracts: A Nash bargaining approach." *Econometrica*, 52, 449-460.

Hart, Oliver D. 1995. *Firms, contracts, and financial structure.* Oxford: Oxford University Press.

Holmstrom, Bengt. 1982. "Moral Hazard in Teams." *Bell Journal of Economics*, 13(2), 324-340.

Katz, Michael L., and Carl Shapiro. 1985. "Network externalities, competition and compatibility." *American Economic Review*, 75(3), 424-440.

Klein, Benjamin. 1988. "Vertical Integration as Organizational Ownership: The Fisher Body-General Motors Relationship Revisited." *Journal of Law, Economics, and Organization*, 4(1), 199-213.

Klepper, Steven. 1996. “Entry, Exit, Growth, and Innovation over the Product Life Cycle.” *American Economic Review*, 86, 562-583.

Mandell, Lewis. 1990. *The Credit Card Industry: A History.* Boston: Twayne Publishers.

MasterCard International. “The Master Card Story.”
http : //www.mastercardintl.com/corporate/the_master_card_story.html downloaded August 24, 2005.

Reed, Ralph T. 1952. “American Express: Its Origin and Growth.” Speech delivered to The Newcomen Society: New York.

Rochet, Jean-Charles, and Jean Tirole. 2003. “Platform Competition in Two-sided Markets.” *Journal of the European Economic Association*, 1, 990-1029.

Rochet, Jean-Charles, and Jean Tirole. 2004. “Two-sided markets: An overview.” Manuscript.

Schiff, Aaron. 2003. “Open and Closed Systems of Two-Sided Networks.” *Information Economics and Policy*, 15(4), 425-442.

Williamson, Oliver E. 1985. *The Economic Institutions of Capitalism.* New York: The Free Press.

Wright, Julian. 2004. “The Determinants of Optimal Interchange Fees in Payment Systems.” *Journal of Industrial Economics*, 52(1), 1-26.