Barriers to network-specific innovation*

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Abstract

We consider incentives for network-specific investment and the implications for network governance. We examine an environment in which participants that make 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 usage of the network is high or no agents invest and usage of the network is low. The high-usage 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, where absence of inter-network competition avoids commitment, network governance will be characterized by mutual ownership by network users.

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1 Introduction

The 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 will obtain in the absence of commitment. For example, in the absence of inter-network competition, optimal monopoly pricing of network usage can avoid one-time investments that would reduce the marginal cost of using the network.

The particular cause of underinvestment will determine how it is mitigated. In environments where a network can commit to prices, underinvestment implies a value to coordination. Coordination will not be sufficient to achieve full investment absent commitment to prices for network usage. In this case, suboptimal investment implies a value for governance mechanisms that can achieve commitment.

The case of Visa is illustrative.\footnote{Cardillo, Martin, and Orlando discuss the Visa case in detail.} Bank Americard, the earliest predecessor to the present day Visa card, had characteristics of a network unable to commit to prices. It could be viewed as a network because more users of 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.
In order to expand the program outside the state of California, Bank of America established BankAmericard Service Corporation to allow licensed banks outside the state to issue cards 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 BankAmericard program to licensed issuers of the card. 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.

This paper develops a model that rationalizes alternative mechanisms of network governance. The model highlights the interrelation of the disincentive to invest in cost-reducing innovation resulting from a network externality and that derivative of a more conventional hold-up problem. Assuming network access is priced at marginal cost, we show a network externality may result in multiple investment equilibria. However, investment disincentives associated with the network problem can be avoided 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. In this case, a governance mechanism that can achieve commitment may be adopted. For example, where the cost of contracting between network users is sufficiently low, commitment may be achieve through joint ownership of network resources.

Table 1 summarizes the results of the paper.

Table 1: Summary of Results
For each of the cases considered, we compare equilibrium allocations with allocations achieved by a central 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. 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 planners 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. A concluding discussion, presented in section 5, suggests the present model has application to a variety of network environments.

2 The environment

The economy is populated by a mass 1 of network participants. Each participant receives total revenue $R$ for payments sent and received on behalf of clients. By assumption, the price charged to clients is independent of whether payments are ultimately sent or received on- or off-network. Consequently, participants desire to minimize the cost of their activity.

Each network participant makes one payment to and receives one payment from each of the other network participants. Payments can be made either on-network or off-network. A fraction $\theta$ 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 $\bar{\phi}$. The off-network cost of trivial payments is $\varphi < \bar{\phi}$. We also assume participants must pay costs $\varphi$ and $\bar{\phi}$ to receive trivial and urgent payments, respectively, off-network.

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. $\delta$ 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

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2 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.

3 For example, participants may be local monopoly providers of banking services.

4 As local monopoly providers of banking services, participants’ retail pricing decisions will be determined by relative demand for products rather than the relative cost of producing these various services. Analysis of optimal pricing at the retail level is beyond the scope of this exercise.
marginal cost of network usage to the network owner is zero.\(^5\)

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 \(\gamma\) and reduce the cost of hooking up to zero. Hence, participants who have paid \(\gamma\) 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>
<thead>
<tr>
<th></th>
<th>Trivial ((1 - \theta))</th>
<th>Urgent ((\theta))</th>
</tr>
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<tbody>
<tr>
<td>Off-network</td>
<td>(\varphi)</td>
<td>(\bar{\varphi})</td>
</tr>
<tr>
<td>On-network w/out investment</td>
<td>(p^{s,r} + \delta)</td>
<td>(p^{s,r} + \delta)</td>
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<tr>
<td>On-network w/investment</td>
<td>(p^s)</td>
<td>(p^r)</td>
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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 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

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\(^5\)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 because of transactions cost and regulatory constrains, or both.
could invest in computer systems to automate inscription coordination. 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 $\gamma$ per participant. Hence the total cost for the mass 1 of participants is $\gamma$. 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

$$C^i = \gamma.$$  \hfill (1)

If the planner does not invest, the cost is

$$C^o = 2[\theta \delta + (1 - \theta) \varphi]$$  \hfill (2)

as the mass of 1 agents send and receive their urgent share ($\theta$) of payments on-network at hook-up cost ($\delta$) while they send and receive their trivial share ($1 - \theta$) of payments off-network at the relevant cost ($\varphi$). 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 $\gamma \leq 2[\theta \delta + (1 - \theta) \varphi]$. 

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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. 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 what other participants do. If the coordinating agent is independent from the network owners, there can be over-investment in the technology.

3.1 The participant investment decision

Let $\lambda$ denote the fraction of participants that invest in the technology. The profits for a cost-minimizing network participant are $\pi^o$ if a participant does not invest and $\pi^i$ if they do. These profits depend on whether or not other participants have invested in the technology.
\[
\pi^o = R - (\theta\delta + (1 - \theta)\varphi) - \lambda\delta - (1 - \lambda)(\theta\delta + (1 - \theta)\varphi), \tag{3}
\]
\[
\pi^i = R - \gamma - (1 - \lambda)(1 - \theta)\varphi. \tag{4}
\]

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 \(\theta\) of payments they make on-network and \(\varphi\) for the trivial share of payments they make off-network. All payments received from the fraction \(\lambda\) 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 \(\varphi\).

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 \(\varphi\)).

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

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

By investing in the technology, participants incur a cost \(\gamma\). On the other hand, they save \(\bar{\delta}\) on the urgent share of payments \(\theta\) both sent and received
on-network. In addition, they save \( \varphi \) 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 \( \lambda \)). The only marginal cost a participant cannot avoid by investing is \( \varphi \) 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

\[
2\theta\bar{\delta} + (1 - \theta)\varphi \leq \gamma \leq 2\theta\bar{\delta} + (1 - \theta)(\varphi + \bar{\delta})
\]

then there are multiple equilibria corresponding to \( \lambda \) values of 0, 1, and \( \lambda' \), where \( \lambda' \) 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 \( \lambda \). We say that an equilibrium \( \lambda \) is unstable if an arbitrarily small deviation from the beliefs necessary to sustain this equilibrium give 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 \( \lambda_\eta \) of participants invest in the technology.

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

It is obvious that \( \lambda' \) 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 \( \gamma \) between these two bounds, both the low-investment and the high-investment equilibrium are stable.
3.2 The coordinator decision

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 at least partly possible to pay for the technology as a variable cost depending on usage, then we can show that the equilibrium with high investment will be unique. In this section, we show an opportunity for coordination exists. A ‘coordinator,’ either a third party or an entity working for the network owners, can invest in the technology on the behalf of network participants and charge them some variable cost.\(^6\)

The coordinator is assumed to face a production function with constant returns to scale; i.e., the innovator must pay a cost \(\gamma\) 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.

The coordinator charges participants on the behalf of whom it invests prices \(q^s\) per payment sent, \(q^r\) per payment received, and a fixed fee \(f\).\(^7\) Let

\(^6\)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 a 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.

\(^7\)We do not restrict \(q^s\), \(q^r\) or \(f\) to be strictly positive.
\(\lambda^c\) denote the fraction of such network participants. Assuming variable prices sufficient 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

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

where \(\lambda\) 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 \((\gamma)\) 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 \(q^r \leq \delta\) assures client-participants will prefer to receive on-network payments through the network-specific technology.\(^8\) 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 for urgent payments received from non-users of the technology. If a high-investment

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\(^8\)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 \(q^r > \delta\) and monitoring is costly enough, participants may have an incentive to ‘unhook’ the technology when they are not sending payments and save \(q^r - \delta\) on payments received.
equilibrium exists, the break-even condition for the coordinator whenever \( \lambda = 1 \) is

\[ f = \gamma - q^s - q^r. \]  \( (8) \)

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

\[ \pi^c = R - f - q^s - \lambda q^r - (1 - \lambda)(\theta q^r + (1 - \theta)\varphi). \]  \( (9) \)

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

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

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

\[ f \leq \theta(\bar{\delta} - \varphi). \]  \( (11) \)

The total cost of the technology to participants is then

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

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 break-even condition for the coordinator 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 $2\theta\delta + (1 - \theta)\varphi \leq \gamma < 2[\theta\delta + (1 - \theta)\varphi]$. 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 $2[\theta\delta + (1 - \theta)\varphi] < \gamma \leq 2\theta\delta + (1 - \theta)(\varphi + \delta)$. 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: Decentralized Equilibrium Investment Shares

Figure 1 illustrates the correspondence between the decentralized $\lambda$ equilibria and the central planner’s allocation in the $\gamma$ parameter space. The remainder of the analysis disregards the unstable equilibria. Instead we fo-
cus exclusively on the two equilibria where either all participants invest or no participant invests.

The departure between the private and social allocations 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 $\gamma$ 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 $\gamma$ 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.\textsuperscript{9}

As $\varphi \to 0$, the range of parameters for which there can be under-investment 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

\textsuperscript{9}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 $2\varphi < \gamma < \varphi + \delta$, 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.

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investors to make payments on-network. In this case, the main concern is that the high-investment equilibrium might occur. As \( \varphi \rightarrow \bar{\delta} \), the range of parameters for which there can be over-investment 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 investors 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 \( 2\theta\bar{\delta} + (1 - \theta)\varphi \leq \gamma \leq 2\theta\bar{\delta} + (1 - \theta)(\varphi + \bar{\delta}) \) then a coordinator can implement the equilibrium with investment while the planner would choose not too. The incentive for the coordinator to do so will depend on whether it is independent of the participant network owners 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, participant network owners 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 participant network owners, these owners cannot simply prevent the coordinator from operating.\(^{10}\) Indeed, since

\(^{10}\)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
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 $\gamma$. It is thus interesting to ask if it might 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 $2[\theta \bar{\delta} + (1 - \theta) \varphi]$ 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

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

which implies

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

Restricting the final allocation to be socially efficient requires a limit on 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

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.

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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

This section has 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 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 appro-
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 externality. Indeed, the main concern seems to be how to prevent over-investment from occurring.

4 The no-commitment case

This section considers the case where the network operator is unable to commit to prices. Instead, the network owner chooses prices $p^s$ for payments sent and $p^r$ for payments received on-network after network participants have made their investment decision. Due to this inability to commit, the equilibrium with high investment generally does not exist. Even with the opportunity for coordination, the high-investment equilibrium can only be implemented under certain pricing schemes. Specifically, the high investment equilibrium only exists if the coordinator can profitably implement a pricing scheme with no fixed cost. And even in that case, if demand for network payments is sufficiently inelastic, the network operator may avoid the high
investment equilibrium. In this case, monopoly profits from a high margin on the low volume of urgent payments dominate monopoly profits from a low margin on the high volume of both urgent and trivial payments.

In contrast to the results discussed in the previous section, these results reflect a hold-up problem that cannot be as easily resolved as was the network effect.\(^{11}\) For example, assume it is not possible for a coordinator to charge only a variable cost. Once the investment in the technology has been made, the fixed cost is sunk and the monopolist will charge participants as much as possible. 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. With monopoly network ownership, 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.

### 4.1 The participant investment decision

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 $\gamma$ falls in the range $2\theta\delta + (1 - \theta)\varphi \leq \gamma \leq 2\theta\delta + (1 - \theta)(\varphi + \delta)$. In this case, we prove the following proposition

**Proposition 4** If the network operator 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 $\gamma$. The network operator can set $p^u = 0$ and $p^r > 0$. Participants will send all payments on-network.

\(^{11}\)Grout (1984), Hart (1995), among others, have shown that specific investment will not be undertaken at the optimal level if contracts are incomplete.
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 The coordination decision

Assume it is not possible for participants to incur only a variable costs for use of the technology. For example, there may be a fixed cost required of participants to learn the technology. Or, as discussed in footnote 8, 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 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 avoid 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, 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.

If the network operator can set \( p^r > 0 \) unrestricted, then the proof of proposition 5 does not go through whenever the coordinator charges no fixed cost. Indeed, since there is no fixed cost to cover in this case, participants are willing to invest in the technology as long as they make at least zero profit. Assuming as in the previous section that \( p^s = 0 \), the network operator cannot charge \( p^r > R - q^s - q^r \) since participants would otherwise exit the market. Hence the high-investment equilibrium exist and is unique.

**4.2.1 Monopoly pricing for network usage when demand is sufficiently inelastic**

If usage of the technology involves only variable costs, the high-investment equilibrium may exist. For example, a monopolist network owner can 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 monopolist is restricted on how much it can charge on payments received, there are parameter values for which only the no-investment equilibrium exists.

Assume the monopoly is constrained and must set $p^r \leq \bar{p}$. In this case, the coordinator may not be able to implement the high-investment equilibrium uniquely. Specifically, this result depends on the elasticity of demand for network access.

**Proposition 6** 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 $\varphi$ 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

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12 This case is particularly interesting in light of policy debates over whether it is ‘fair’ to be charged for transactions one did not initiate.
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 \( \bar{p} > 0 \). ■

The intuition for this result is that the monopolist network owner may make more profits by charging a high price on urgent payments only than 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 inelastic enough, the monopolist prefers to set a high price and restrict quantity.

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 \((\frac{1-\theta}{1+\theta})(\frac{\bar{\varphi}+\varphi}{\bar{\varphi}+\varphi})\). 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.

Figure 2: Demand for Sending Payments On-network, \( p^* = q^* = 0 \)
4.3 Comparison with the planner’s allocation

Proposition 4 shows that for all values of $\gamma > 0$, the 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 $0 < \gamma < 2\theta \bar{\delta} + (1 - \theta) \varphi$. 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. To begin, consider the case where the coordinator is independent of
the network owner. In this case, proposition 5 shows that the high-investment equilibrium cannot be implemented 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 high-investment equilibrium can be implemented if the demand curve is elastic. In that case, however, there will be over-investment if \( \gamma > 2[\theta \delta + (1 - \theta) \varphi] \), in which case the planner would not invest but the coordinator does. If instead the demand curve is inelastic, then Proposition 6 shows there will be under-investment whenever \( \gamma < 2[\theta \delta + (1 - \theta) \varphi] \).

It may be possible for the network operator to subsidize the fixed cost paid by participants in order to implement the high-equilibrium allocation. In this case, we must assume that the monopoly network operator also owns the coordinator. If any price \( p^r \) can be charged for payments received, then the monopolist will subsidize the fixed cost of investing in the technology. It can extract all the surplus from payments received over the network and thus wants to maximize network usage. In this case, there will be over-investment if \( \gamma > 2[\theta \delta + (1 - \theta) \varphi] \).

It should be noted that, in certain cases, it might be difficult to subsidize the fixed cost involved in investing in the technology. For example, if this cost is random, it might be very costly to provide a fix enough subsidy up front to convince participants to invest. If the subsidy is not paid up front, then lack of commitment becomes an issue again. In certain cases, such as networks that are owned by a government, it may be politically infeasible for the network to subsidize participant investment.

For the same reason as above, 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 under-investment whenever
\[ \gamma < 2[\theta \delta + (1 - \theta)\phi]. \]

This problem illustrates an interesting feature of two-sided markets. 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 6 is that the monopoly that owns the network should be allowed to charge for payments received through the network. The charge for payments made through the network should be kept to a minimum.\(^{13}\)

5 Discussion

This model is representative of several cases of network environments. The Fedwire system, for example, allows bank patrons to transfer funds between banks. 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. 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 automa-

\(^{13}\)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.
tion of the retail Fedwire transaction? One explanation for this persistent price differential is that the first-mover cannot justify the expense of retail-interface innovation, even if the last-mover could. Alternatively, monopoly wholesale pricing will limit network utilization and may hold-up investment in retail-cost-reducing innovation altogether. The present model suggests under-investment in Fedwire-specific technology may be a result of a hold-up problem associated with the network owner's inability to credibly commit to not appropriate the value of any such network-specific investment. Indeed, the model suggests that an investment coordinator that can subsidize banks’ fixed costs of technology adoption can overcome investment disincentives associated with the network effect. Consequently, the present results may be of interest to policymakers concerned with increasing utilization of Fedwire network assets.

The case of revolving-credit programs (credit cards) is also illustrative. Essentially, such a program is a system of accounts that allows merchant and consumer patrons of the revolving-credit service to exchange goods and services without carrying cash. Absent a cost-effective retail interface (i.e. the swipe card), patrons could still make use of the system, though doing so would be costly. Individual merchants might have an incentive to create a cost-effective retail interface. As suggested by the model, however, a network externality would suggest the incentive to invest in such an innovation would depend on the investment decisions of other merchants. Also as suggested by the model, if the network externality were the only factor resulting in sub-optimal investment, an independent coordinator could invest on behalf of merchants and implement the high-investment equilibrium. However, monopoly ownership of the underlying network would hold-up such investment. Consequently, it is unsurprising that the creation of the VISA
coincided with a transfer of the network assets from Bank of America—which owned BankAmericard, the card VISA was replacing—to the card issuing banks.

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, monopoly ownership is also a feature representative of many network environments. This paper presents a model that combines a network externality with a hold-up problem to illustrate the relationship between these phenomena. The analysis suggests that, absent the expectation of an optimal monopoly-network-access price, a number of pricing schemes would allow a coordinator to implement high-investment in network-specific technology. If the network is monopoly owned, however, monopoly pricing will hold-up investment associated with any measure of fixed costs.
References


Outline

Introduction

The paper emphasizes the role of (the absence of) commitment as a barrier to investment on a network. We show that with commitment, the multiplicity of equilibria resulting from a network effect can be eliminated by the introduction of a ‘coordinator’ (a price schedule that transforms the fixed cost of investing into a combination of fixed and variable costs). In the absence of commitment, however, a hold up problem prevents the high investment equilibrium. We discuss how, in practice, networks have addressed these problems.

Planner’s problem

The case with commitment

- Decentralized investment: multiple equilibria
- Coordinated investment: unique equilibrium

Note, with commitment the ownership structure does not matter (for efficiency). The monopolist can commit to prices and has no incentive to eliminate the high investment equilibrium. On the other hand, with decentralized investment, the monopolist cannot uniquely implement the high equilibrium. Hence, the same equilibria exist. However, the monopolist is able to extract rents. So ownership structure will influence rents, but not efficiency (is that Coase?).

The case without commitment

- Decentralized investment: unique low investment equilibria
- Coordinated investment: low investment when demand is inelastic

Examples