Hold-up on a monopoly-owned network*

Antoine Martin Michael J. Orlando

Federal Reserve Bank of Kansas City

March 2004

Preliminary and incomplete

Abstract

We consider an environment in which participants make payments over a network and 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 through introduction of a coordinator. Under monopoly network ownership, however, a hold-up problem results in implementation of the low usage equilibrium.

Keywords: Hold-up, Network
JEL classification: L14

*We thank Jamie McAndrews for useful comments. The views expressed here are those of the authors and not necessarily those of the Federal Reserve Bank of Kansas City or the Federal Reserve System.

1 Introduction

The demand externality is typically featured 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 will fall below the social optimum. Where network assets are monopoly-owned, however, the network effect may be only one factor depressing network usage. A more conventional hold-up problem may avoid one-time investments that would reduce the marginal cost of using the network. Understanding the interrelation between these mechanisms is an important first-step toward design of effective policy to encourage more efficient utilization of resources on monopoly owned networks.

The case of Fedwire is illustrative. Biehl, McAndrews, and Stefanadis (2002) suggest the large differential between wholesale and retail prices for Fedwire transfers results in low utilization of network assets. 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 may hold-up potential investments in retail-cost-reducing innovation.

This paper develops a model to illustrate 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 externality may result in multiple investment equilibria. However, an agent that is able to coordinate investment activity can avoid the disincentives associated with the network problem. In contrast, except in very special cases, under monopoly ownership of network assets, optimal monopoly pricing of network usage results in hold-up of even coordinated investment and, hence, underutilization of

network resources. Our results illustrate that the hold-up problem may be of greater concern than the network effect and thus merits the attention of researchers and policy makers.

We also 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. We provide conditions such that socially-inferior equilibria are not implemented when network utilization is priced a marginal cost.

The next section specifies the environment. Two ownership structures for the network are then considered. Section 3 provides an analysis of a mutually-owned network. Multiplicity of equilibria are shown to exist given feasible restrictions to the network access price. However, the high-investment equilibrium may be implemented if investment is coordinated by a single agent. Section 4 examines participant investment assuming monopoly ownership of network assets. Welfare implications are explored in section 5. A concluding discussion is presented in section 6.

2 The environment

Assume the economy is populated by a mass 1 of network participants. Each participant is a local monopoly provider of payment services, receiving 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 θ of the payments each participant must make are assumed to be time-sensitive or 'urgent'. The cost of making such a payment off-network is $\bar{\varphi}$. The remaining share of payments are assumed to be non-time-sensitive or 'trivial'. 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.

The cost of making and receiving payments on-network does not depend upon whether the payment is urgent or trivial. But it does depend on whether an investment has been made in a network-specific technology. If no investment has been made, participants must pay $p^s + \delta$ for each payment sent and $p^r + \delta$ for each payment received over the network. δ can be thought of as the participant resource cost of 'hooking up' to the network whereas p^s and p^r are usage prices set by the network owner. We assume $\varphi < \delta < \bar{\varphi}$.

Each participant can choose to pay γ to invest in a technology that reduces 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. The marginal cost of network usage is assumed to be zero.

To fix ideas, consider the following analogy. Payments can either be sent over an electronic network or sent as a check by mail. Because the mail is slow, urgent payments sent off-network would require a premium, perhaps for a courier service. Since on-network payments are relatively fast, there is no between urgent and trivial payments. The costs incurred when payments are sent this way correspond to both the labor of coordinating inscription into bank ledgers and the network usage fee. Alternatively, banks could invest in computer systems that automate inscription and on-network costs would be limited to fees paid for network usage.

3 Mutually-owned network: a network effect

If the network is *mutually*-owned by participants, then assume $p^s = p^r = 0$. Indeed, since participants jointly own the network, they charge the marginal cost. 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.

Participants will invest in the network-specific technology if sufficiently many other participants do, and will not if sufficiently few do. Assuming investment can be coordinated by a single agent ensures implementation of the high-investment equilibrium.

3.1 Decentralized investment: multiple equilibria

Let λ denote the fraction of participants that invest in the technology. Assuming mutual ownership of network assets yields marginal cost pricing, we calculate the profits for a network participant depending on whether or not investment in the technology has been made. These profits are denoted π^i and π^o, respectively.

$$\pi^o = R - (\theta\delta + (1-\theta)\varphi) - \lambda\delta - (1-\lambda)(\theta\delta + (1-\theta)\varphi), \tag{1}$$

$$\pi^i = R - \gamma - (1-\lambda)(1-\theta)\varphi. \tag{2}$$

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

Equation (1) indicates participants who have not made the investment pay δ 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 that have made the investment come on-network at a price δ. 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 δ while the remainder are received off-network at price φ.

Equation (2) 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

$$\gamma \leq 2\theta\delta + (1-\theta)(\varphi + \lambda\delta). \tag{3}$$

By investing in the technology, participants incur a cost γ. On the other hand, they save δ 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 δ 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 $\gamma \leq 2\theta\delta + (1-\theta)\varphi$ then participants will invest in the technology regardless of what other participants do. Similarly, if $\gamma \geq 2\theta\delta + (1-\theta)(\varphi+\delta)$

participants will not invest regardless of what others do. Parameters in these ranges yield unique equilibria. However, if

$$2\theta\delta + (1-\theta)\varphi \leq \gamma \leq 2\theta\delta + (1-\theta)(\varphi + \delta) \tag{4}$$

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

We can define a notion of stability of these equilibria with respect to small deviations of network participants' beliefs about λ. Let $\hat{\lambda}$ denote those beliefs.

Definition 1 *An equilibrium λ is unstable if, $\forall\varepsilon > 0$, $|\hat{\lambda} - \lambda| > \varepsilon \Rightarrow \lambda$ is not an equilibrium.*

It is obvious that $\lambda^{'}$ is not stable. If $\gamma \geq 2\theta\delta + (1-\theta)\varphi$ a low-investment equilibrium is stable. Alternatively, if $\gamma \leq 2\theta\delta + (1-\theta)(\varphi + \delta)$ 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. The remainder of the analysis disregards the unstable equilibrium. Instead we focus exclusively on the two equilibria where either all participants invest or no participant invests.

3.2 Coordinated investment: uniqueness of high-investment equilibrium

This section specifies a number of conditions for the cost and pricing of the network-specific technology that can ensure the high-investment equilibrium will be implemented. A coordinator is introduced who invests on

behalf of network participants. Variable-, fixed-, and mixed-price schemes are proposed that can ensure demand for on-network payments is sufficient to implement the high-investment equilibrium. A special case is discussed in which the investment represents a cost-reducing innovation in network usage. In such an event where investments may be duplicative, complete property rights allow the innovator to obtain non-negative profits by implementing the high-investment equilibrium.

3.2.1 A variable-price scheme

Consider the present environment with a coordinating agent who can invest in the network-specific technology at a total cost proportional to the share of participants installing the technology via the coordinator. We denote this share by λ^c. The coordinator then charges these participants for the resulting service flow prices q^s per payment sent and q^r per payment received. Break-even prices are 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 (4).

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

$$\pi_v^{CSP} = -\lambda^c\gamma + \lambda^c q^s + \lambda^c[\lambda q^r + (1-\lambda)\theta q^r] \tag{5}$$

where λ is the 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. Assuming $q^s \leq \varphi$,

client participants will prefer to send even trivial payments over the network. The coordinator receives q^r for payments received by clients from other 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 equilibrium exists, the break-even condition for the coordinator whenever $\lambda = 1$ is

$$q^r = \gamma - q^s. \tag{6}$$

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

$$\pi_v^c = R - q^s - \lambda q^r - (1-\lambda)(\theta q^r + (1-\theta)\varphi). \tag{7}$$

Participants pay q^s for both urgent and trivial payments sent on-network. They also pay q^r for all payments received from other users of the technology. Finally, they pay q^r for urgent payments received from non-users of the technology and φ for trivial payments received from these participants. Participants will choose the technology through the coordinator if $\pi_v^c \geq \pi^o$, which is true if and only if

$$q^s + \lambda q^r + (1-\lambda)\theta q^r \leq 2\theta\delta + (1-\theta)(\varphi + \lambda\delta). \tag{8}$$

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

$$q^r \leq (1+\theta)\delta - \theta\varphi. \tag{9}$$

and the total cost to participants is

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

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

$$q^s + \lambda q^r + (1-\lambda)\theta q^r \leq \gamma. \tag{11}$$

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

$$q^r \leq \gamma - \varphi. \tag{12}$$

That is, $q^s + q^r \leq \gamma$ 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 (10) to $2\theta\delta + (1-\theta)(\varphi+\delta)$, it is obvious that if parameters are in the range of multiple equilibria specified by condition (4) the total cost to participants when prices are chosen to assure $\pi_v^c \geq \pi^i$ is less than the total cost when prices are chosen to assure $\pi_v^c \geq \pi^o$. And these prices satisfy the break-even condition for the coordinator specified in equation (6).

The following proposition summarizes the results of this section.

Proposition 1 *The innovator can implement the high-investment equilibrium uniquely.*

It should be noted the coordinator cannot make positive profits when its total cost is proportional to the number of participants that invest. Indeed, in this case a positive profit would imply that the total cost for a participant of gaining access to the technology via the coordinator, whenever $\lambda = 1$, is greater than when investing directly. Thus it cannot be an equilibrium for all agents to invest via the coordinator in this case.

For γ sufficiently high in the parameter range specified by condition (4), however, one can show that $q^r > \delta$. In the event under the present pricing scheme, support of proposition (1) requires an implicit assumption regarding the behavior of participants. Specifically, participants must be prohibited from 'unplugging' the technology while not sending payments, an action they would prefer to take since the cost of receiving on-network payments through the technology (q^r) is greater than that of receiving payments around the technology (δ). The fixed-price scheme considered in the next section avoids variable prices that yield ex-post incentives for such hidden action.

3.2.2 A fixed-price scheme

Again, consider the present environment with a coordinating agent who can invest in the network-specific technology at a total cost proportional to the share of participants installing the technology via the coordinator, λ^c. The coordinator then charges participants a fixed price γ if a mass 1 of participants acquire the technology and 0 otherwise. The coordinator does not charge for payments made or received using the technology. If a positive mass of participants do not acquire the technology, the coordinator goes bankrupt and suffers a loss γ. All participants keep the technology they have acquired and pay nothing to the coordinator. In this case, the coordination service provider's profits are

$$\pi_f^{CSP} = -\lambda^c \gamma + \lambda^c f \tag{13}$$

implying a break-even condition of the coordinator of

$$f = \gamma. \tag{14}$$

If π_f^c, are the profits of a participant who acquires the technology through the coordinator, assuming a fraction λ of participants have acquired the technology then

$$\pi_f^c = R - f - (1-\lambda)(1-\theta)\varphi, \tag{15}$$

where λ is the share of participants with access to the network-specific technology through either the coordinator or their own investment.

If $\lambda < 1$, then $\pi_f^c - \pi^i = \gamma > 0$ and $\pi_f^c - \pi^o = 2\theta\delta + (1-\theta)(\varphi + \lambda\delta) > 0$. Thus, in the event all participants do not use the technology, $f = 0$ and participants prefer to acquire the technology through the coordinator rather than on their own or not at all.

If, instead, $\lambda = 1$, then $f = \gamma$. In this case, participants will choose the coordinator over no access to the technology if $\pi_f^c \geq \pi^o$ which is true if and only if

$$f \leq 2\theta\delta + (1-\theta)(\varphi + \delta). \tag{16}$$

For participants to choose the coordinator over own investment, $\pi_f^c \geq \pi^i$, which is true if and only if

$$f \leq \gamma. \tag{17}$$

Since $\gamma \leq 2\theta\delta + (1-\theta)(\varphi + \delta)$ in the range of multiple equilibria defined by condition (4), the fixed price necessary for participants to prefer the coordinator to own investment (17) is sufficiently low for participants to prefer the coordinator to no investment as well (16). And, at this price, the coordinator breaks even (14).

For all λ under this pricing scheme, participants are at least as well off acquiring the technology through the innovator as they are either not acquiring the technology or acquiring it on their own. Thus, along the equilibrium path, all participant acquire the technology and the innovator recovers its cost.

Unlike under the variable-price scheme, marginal prices under the fixed-price scheme do not result in ex-post incentives for participant action that would avoid the high-investment equilibrium. However, support of proposition (1) under the fixed price scheme requires an implicit assumption regarding symmetry of information between participants and the coordinator. Specifically, the nature of the technology must be such that the coordinator can costlessly verify false claims of off-network receipts by participants. The variable prices derived for the mixed-price scheme considered in the next section ensure information symmetry between the coordinator and participants while being sufficiently low to avoid ex-post incentives for hidden action.

3.2.3 A mixed-price scheme

Again, consider the present environment with a coordinating agent who can invest in the network-specific technology at a total cost proportional to the

share of participants installing the technology via the coordinator, λ^c. The coordinator then charges these participants for the resulting service flow prices q^s per payment sent, q^r per payment received, and a fixed fee f. The fee f is charged regardless of the number of participants who acquire the technology. 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 (4).

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

$$\pi^{CSP} = -\lambda^c\gamma + \lambda^c f + \lambda^c q^s + \lambda^c[\lambda q^r + (1-\lambda)\theta q^r] \tag{18}$$

where λ is the 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 client participant 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 participants will prefer to receive on-network payments through the network-specific technology. The coordinator receives q^r for payments received by clients from other 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 equilibrium exists, the break-even condition for the coordinator whenever λ

$= 1$ is

$$f = \gamma - q^s - q^r. \tag{19}$$

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

$$\pi^c = R - f - q^s - \lambda q^r - (1-\lambda)(\theta q^r + (1-\theta)\varphi). \tag{20}$$

Equation (20) includes all the cost terms deducted from participant revenues under the fixed- and variable-pricing schemes (equations (15) and (7), respectively). Participants will choose the technology through the coordinator if $\pi^c \geq \pi^o$, which is true if and only if

$$f + q^s + \lambda q^r + (1-\lambda)\theta q^r \leq 2\theta\delta + (1-\theta)(\varphi + \lambda\delta). \tag{21}$$

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

$$f \leq \theta(\delta - \varphi). \tag{22}$$

The total cost of the technology to participants is then

$$f + q^s + q^r \leq (1+\theta)\delta + (1-\theta)\varphi. \tag{23}$$

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

$$f + q^s + \lambda q^r + (1 - \lambda)\theta q^r \leq \gamma. \tag{24}$$

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

$$f \leq \gamma - \varphi - \delta. \tag{25}$$

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 (23) to $2\theta\delta + (1 - \theta)(\varphi + \delta)$, it is obvious that if parameters are in the range of multiple equilibria specified by condition (4) 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 (19).

The variable prices derived for the mixed-price scheme ensure information symmetry between the coordinator and participants while being sufficiently low to avoid ex-post incentives for hidden action. Unlike under the variable-price scheme, variable prices under the present scheme are sufficiently low to ensure participants prefer to receive all payments through the coordinator-provided technology. Moreover, unlike under the fixed-price scheme, positive variable prices used in the present scheme convey information back to the coordinator regarding method of payment. Under the set of prices derived in this section participants choose to invest with the coordinator regardless

of their belief about λ.

3.2.4 Discussion: cost duplication and property rights

The preceding sections have focused on the coordinating function of an 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 centralized 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 the contracting and enforcement costs presented as qualifications to the results of Sections (3.2.1) and (3.2.2).

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 must not only overcome the coordination problem specified above. 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.

4 Monopoly-owned network: hold-up

This section introduces monopoly ownership of the network. The monopolist chooses profit maximizing prices p^s for payments sent and p^r for payments received on-network. The monopolist network owner is assumed to be unable to commit to any particular prices p^s and p^r prior to participant investment. Due to this inability to commit, the equilibrium with high investment does not exist whenever investment decisions are decentralized. Moreover, under most circumstances a coordinator is unable to guarantee implementation of the high-investment equilibrium under optimal monopoly prices. Specifically, the high investment equilibrium only exists under a variable-price scheme when two assumptions are met. First, variable prices charged by the coordinator imply no fixed costs of technology adoption for the participant, not even a small cost of start-up. Second, the cost of sending urgent payments out-of-network, $\bar{\varphi}$, must be sufficiently low so that monopolist profits from a low margin on the high volume of both urgent and trivial payments dominate monopolist profits from a high margin on the low volume of urgent payments only.

In contrast to the results discussed in the previous section, these results reflect a hold-up problem that dominates the network effect. 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.

4.1 Decentralized investment: hold-up

Consider the case of decentralized investment by participants in a technology specific to a monopoly-owned network. Recall from equation (4) that multiple equilibria exist in the event that γ 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 2 *If the network is owned by a monopolist 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 monopoly 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 monopolist 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 monopolist 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: hold-up

Assume it is not possible for the coordinator to charge only a variable cost for the technology. For example, there may be a fixed cost required of participants to learn the technology. Or, as discussed in section (3.2.1), perhaps 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 cannot exist.

Assume, without loss of generality, the 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 cost.

Proposition 3 *When the coordinator charges some fixed cost and the network is owned by a monopoly, only the no-investment equilibrium exists.*

Proof. By way of contradiction, suppose that all participants acquire the technology through a coordinator. If the monopolist 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 monopolist 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 monopolist pricing behavior, participants prefer not to invest in the technology. ■

If usage of the technology involves only variable costs, the high-investment equilibrium may exist. However, we show that if the monopoly is restricted on how much it can charge on payments received, there are parameter values for which only the no-investment equilibrium exists.

If the monopoly can $p^r > 0$ unrestricted, then whenever the coordinator charges no fixed cost the proof of proposition 3 does not go through. Indeed, since there is no fixed cost to cover, 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 monopolist cannot charge $p^r > R - q^r$ since otherwise participants exit the market. Hence the high-investment equilibrium exist and is unique.

Now assume the monopoly is constrained and must set $p^r = \bar{p}$. We show the coordinator may not be able to implement the high-investment equilibrium uniquely.

Proposition 4 *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. Assume, without loss of generality, 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 if $p^s = \varphi$ and is equal to φ. 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 if $p^s = \bar{\varphi}$ and is equal to $\theta\bar{\varphi}$. 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 if $\gamma \leq 2\theta\delta$ 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 may make more profits by charging a high price on urgent payments only than charging a lower price on all payments. This depends on whether or not the demand curve is inelastic enough. In our simple model, the demand curve really has two points: Either all payments go through the network or only urgent payments do. The demand curve is more 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 greater. Hence, if the demand curve is inelastic enough, the monopolist prefers to set a high price and restrict quantity. Clearly this result extends to a more realistic model where the demand curve is not restricted to be two points.

An interesting policy implication from this proposition is that the monopoly that owns the network should charge for payments received through the network but not payments made.

5 Some welfare results

In this section, we derive the parameter values for which a planner chooses to invest. We then show that in equilibrium there can be either too little investment or too much investment. We also show how constraints can be imposed so that the coordinator only implements the high-investment equilibrium when it is efficient to do so.

5.1 The planner's problem

Consider the problem for a planner who must decide whether to invest in the technology. Network usage prices are set at the marginal cost of zero. The cost of the technology to the planner 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. We assume the planner cares only about payments being made and thus wants to minimize the cost of this activity.

The cost if the planner invests is

$$C^i = \gamma. \tag{26}$$

If the planner does not invest, the cost is

$$C^o = 2[\theta\delta + (1-\theta)\varphi]. \tag{27}$$

as the mass of 1 agents send and receive their urgent share (θ) of payments on-network at hook-up cost (δ) 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 5 *A planner will invest in the technology whenever* $\gamma \leq 2[\theta\delta + (1-\theta)\varphi]$.

Contrasting the participant investment rules from the mutually-owned network case to that of the central planner presented in Proposition (5) yields Proposition (6).

Proposition 6 *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 is 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 is above the social optimum. ■

Too little investment occurs if 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. Conversely, if participants expect others to invest in the technology there can be too much investment. If the cost of investment is sufficiently high with respect to the central planner's investment rule, it can be individually rational for a participant to invest even if it would have been socially optimal for all participants not to invest.

5.2 Mutually-owned network equilibria

Since a coordinator can uniquely implement the high-investment equilibrium on a mutually-owned network, it is interesting to ask if it is possible to constrain the coordinator's activity when the high-investment equilibrium is not socially efficient. From proposition 5 a planner chooses to invest in the technology whenever $\gamma \leq 2[\theta\delta + (1-\theta)\varphi]$. Hence, a set of constraints that assures the coordinator cannot raise revenue in excess of $2[\theta\delta + (1-\theta)\varphi]$ 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 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 $q^r = \delta$ for payments received. Let $\tilde{f}$ denote the fixed cost. The coordinator can raise revenue of at most $\varphi + \delta + \tilde{f}$. The condition

$$\varphi + \delta + \tilde{f} \leq 2\theta\delta + 2(1-\theta)\varphi \tag{28}$$

is equivalent to

$$\tilde{f} \leq (2\theta - 1)[\delta - \varphi]. \tag{29}$$

When the right hand side of this inequality is positive ($\theta \geq 0.5$), the coordinator should not be allowed to charge a fixed cost greater than this bound. When the right hand side of the inequality is negative ($\theta < 0.5$), the coordinator should be charged a fixed fee equal to that bound in order to have the right to operate. The proceeds from the fee 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.

5.3 Monopoly-owned network equilibria

Section 4 showed that, under most circumstances, when the network is owned by a monopoly only the low-investment equilibrium can arise. In the region of the parameter space where the planner would choose such an equilibrium, the monopoly does not create any inefficiencies. Indeed, in this simple model, the monopoly simply extracts all the rent from the network participants but does not introduce distortions. In the region of the parameter space where the planner would choose the high-investment equilibrium, the monopoly gives

rise to an inefficiency since investment in the technology is suboptimally low due to the hold-up problem.

6 Discussion

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

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.