Regulating Private Infrastructure Investment: Optimal Pricing for Access to Essential Facilities*

by

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This paper analyses optimal pricing for access to essential facilities in a competitive environment. The focus is on investment incentive issues arising from regulation under complete information. To that end, examining the provision of a natural monopoly infrastructure with unlimited capacity, it is shown that the fixed component of a regulated access price can be structured so as to induce a "race" between market participants to provide the infrastructure. An appropriate pricing formula can ensure that a single firm chooses to invest at the socially optimal time (taking into account producer and consumer surplus) despite the immediate access granted to rivals and the non-existence of government subsidies. Under the optimal pricing formula, firms choose their investment timing based on their desire to pre-empt their rivals. This pricing formula is efficient (a two part tariff), implementable ex post, and robust to alternative methods of asset valuation (replacement or historical cost). When firms are not identical, the access pricing formula resembles, in equilibrium, a fully distributed cost methodology. *Journal of Economic Literature* Classification Numbers: L40 (Antitrust Policy) and L50 (Regulation).

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One of the most important issues in the economics of regulation is how to encourage firms to invest in infrastructure in an optimal manner. This is particularly so when that infrastructure involves a natural monopoly technology, e.g., a new broadband network in telecommunications. In such instances, it is socially optimal to have a single provider of the infrastructure and for other firms in the industry to utilise the facility through access arrangements (Armstrong, Cowan and Vickers, 1994; Laffont and Tirole, 1994).

The difficulties of achieving this in an unregulated environment are well known. In general, a vertically integrated infrastructure provider has an incentive to restrict access to the facility so as to enhance its competitive position downstream.[1] A facility owner who is not integrated downstream will also attempt to manipulate access arrangements to maximise monopoly rent appropriation. While the mechanisms by which foreclosure or monopolisation is achieved are imperfect, the risk of bottleneck monopoly power being extended downstream remains.

Regulation of the monopoly element is the favoured solution in such environments. However, regulation carries its own risks. Optimal forms of regulation usually involve non-linear prices so that infrastructure usage charges reflect short-run marginal or incremental costs, while fixed access charges are set with a view for compensating providers for sunk investment costs or fixed on-going costs. The problem is that, to the extent that regulation is effective in promoting downstream competition, it is also effective in dissipating industry rents to consumers. Accordingly, competition can mean that infrastructure providers have too little incentive to invest

[1] Strictly speaking, this incentive only arises where efficient non-linear access prices cannot be charged or there is another type of contractual incompleteness. See, for example, Rey and Tirole (1996) and de

in such facilities. There is a sense in which, as is done by patents for innovation incentives, it is best to allow providers some monopoly power in order to encourage infrastructure investment incentives.[2]

The purpose of this paper is to examine this regulatory problem in more detail. I ask *whether there exists a regulated access-pricing rule that could encourage socially optimal infrastructure investment decisions while preserving maximal downstream competition*? In particular, I search for a mechanism that does not require the use of explicit taxes and subsidies. At first blush, this seems like an impossible task. After all, the socially optimal infrastructure investment decision requires the provider to internalise all of the social benefits, including increments to consumer surplus. Unless perfect price discrimination is enforced, this would appear to require, at the very least, some government subsidy to the provider to take into account the benefits to consumers and the losses resulting from the competitive effects of easy access.

The idea in this paper is to demonstrate how an access regime can be used to create competition between industry participants over the provision of infrastructure. This competition resembles a winner-take-all auction with investment incentives determined by the difference between winning and losing for the individual firms. If a firm wins, it becomes the provider and receives access payments from others. If it loses, it will either pay for access or duplicate the infrastructure at a later date. By committing to an appropriate access pricing formula, the

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Fontenay and Gans (2000). The survey by Mandy (2000) highlights precisely how this may lead to non-price discrimination.

[2] See Armstrong, Cowan and Vickers (1994) for a discussion. King and Maddock (1996) consider the rationale behind the patent system and suggest that it may also be applicable when addressing the effects of access regulation on investment. Price caps are also a means by which regulated firms can accrue rents

regulator can directly determine the difference between winning and losing for firms, raising it if necessary, in order to increase private investment incentives to their social level. So long as there exists sufficient industry rents under competition to finance the investment, it is shown that competition for infrastructure provision can yield to a socially optimal outcome. That is, investments are made at the socially optimal time and others seek access immediately.

The model below focuses on the timing in infrastructure investment decisions using a variant of the model of R&D rivalry developed by Katz and Shapiro (1987).[3] The investment timing issue is a critical one in the infrastructure context. Delayed investment also means delaying the social benefits that flow from the infrastructure. Against that is an incentive wait for new technologies that reduce infrastructure costs or improve its quality; thereby, avoiding becoming locked in to an inefficient set of assets. Such timing issues are critical in industries such as telecommunications which is a critical input in many other industries, making delay costly, but where the technological environment generates high option value to waiting.[4]

This trade-off exists at both a social and private level. However, private infrastructures will base investment decisions on private rather than social returns. That said, two motives for investment are identified in this context – a direct and strategic motive. The direct motive is guided by the infrastructure provider's willingness-to-pay for the investment; that is, the increments to profits it provides. In the absence of competition, a provider chooses investment

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from expenditures on cost reduction (see Laffont and Tirole, 1999).

[3] This type of model originated with Dasgupta and Stiglitz (1980) and has been, subsequently, explored by Fudenberg and Tirole (1984) and Riordan (1992). It is perhaps more appropriately applied to the infrastructure investment context than for R&D. This is because the model does not have any uncertainty associated with the realisation of the investment. With R&D devoting resources to investment is more likely to yield a uncertain realisation of an innovation (Reinganum, 1989). With infrastructure, a given investment will determine a completion date more precisely.

timing by trading off the value of obtaining this increment sooner with the reduced costs afforded by exogenous technological progress (that lowers the investment cost itself). Expectations of competition therefore, diminish the benefits as the provider's profits are reduced; thereby, resulting in delayed investment from a social perspective.

If this were the only motive governing investment timing, the regulatory task of achieving socially optimal timing and maximal competition would be impossible. Without a subsidy, even a monopolist would not provide the infrastructure in a timely manner. However, in this context, a provider may also have an incentive to *pre-empt* other potential providers of the infrastructure. By being the first to build a facility with natural monopoly characteristics, a firm reduces (and perhaps eliminates) the incentive for rivals to duplicate the facility. Without regulation, this typically skews the competitive environment in favour of the provider, sometimes to the point of monopoly. Thus, alternative providers race to become the provider to earn the rents of winning as opposed to losing. It is well known that, in an unregulated environment, investment might take place earlier than the socially optimal date (Reinganum, 1989).

A regulated access price can alter both the willingness-to-pay and pre-emption motives of industry participants. In particular, it can determine the size of the "prize" accruing to a provider at any given date. By making the "prize" negative for dates before the socially optimal timing date and positive, thereafter, it is possible to alter the strategic decision of firms such that one firm invests at the socially optimal date. This is despite (and indeed because of) the expectation that rivals will be able and willing to seek access immediately, thereby, dissipating

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[4] See, for example, Hausman (1997) for a discussion of such trade-offs.

any monopoly rents. The provider realises that, by delaying investment, it risks being pre-empted and having to apply for access themselves on increasingly unfavourable terms.

The access pricing formula that achieves this outcome has several important characteristics. First, it is a more *efficient* price than access prices based purely on usage of a facility. Instead, it is a two-part tariff with the usage charge set optimally as if there were no fixed costs (subject to a feasibility qualification),[5] and a fixed charge. The contribution of this paper is to develop a rationale behind this latter component in access pricing regimes. As has been mentioned by many regulatory economists (e.g., Armstrong, Cowan and Vickers, 1994), fixed charges should be set so as to allow efficient recovery of investment costs. The price derived in this paper fulfills that function as well as becoming a device for manipulating investment incentives themselves. It is based in part on the (replacement) cost of the infrastructure and on the flow of social benefits generated. Thus, in effect, it forces firms to mimic socially optimal incentives in their own strategic timing decision.

A second important feature of the pricing formula is that it is *implementable* ex post. That is, the regulator, while committing to the formula itself, need only use information available at the time access is sought to settle on the realised access price. Indeed, it is robust to alternative methods of asset valuation.

Finally, the equilibrium (realised) access charge resembles a *fully distributed cost* (FDC) allocation scheme. If a symmetric duopoly is the expected competitive structure, the firms contribute an equal share towards the incentive costs. Such schemes have been criticised

[5] This per unit charge can also be adjusted optimally away from short-run marginal cost to reflect incentive difficulties posed by asymmetric information or other competitive concerns (see Vickers, 1995; Armstrong,

by economists because of their lack of an efficiency rationale (Baumol, Koehn and Willig, 1987). However, here the FDC allocation is an equilibrium implication only. When investment is delayed (relative to the social optimum), the seeker pays a greater proportion of realised costs, while, if it is sped up, the reverse is true. So, despite the observed similarities with FDC, this mechanism is part of any regulated pricing commitments.

The prior literature on regulated access pricing has been concerned with difficulties in setting charges in a static environment. In particular, there has been much analysis on the role of asymmetric information in altering regulated access prices (Laffont and Tirole, 1994; Armstrong, Doyle and Vickers, 1996). The present paper does not involve any information asymmetries so as to focus on the first-best form of fixed access charges. When dynamic issues have been addressed in the literature these have dealt with issues of incremental cost improvements under price cap regulation (Armstrong, Cowan and Vickers, 1994) and developing incentives for optimal bypass (Laffont and Tirole, 1993). Of course, the idea of using competition to set prices of regulated monopolies was first suggested by Demsetz (1968). He considered a context in which there was no possibility of competition so that the issue was one of price regulation rather than investment incentives per se. Closest to the work in this paper is that of Gans and Williams (1999). In that paper, competition issues in access regulation are set aside and the focus is on the timing of investment decisions in an environment where provider and seeker engage in negotiations subsequent to any investment taking place. Like the present model, the model of Katz and Shapiro (1987) is employed to analyse the optimal regulated fixed access charge. It is demonstrated that a form of fully distributed costs is optimal as this

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Doyle and Vickers, 1996).

implements the Lindahl price for the provision of the infrastructure, that itself carries a public good element. The present paper relaxes a critical assumption in the earlier paper – that the access provider and seeker do not compete with one another and that there is little consumer surplus flowing from the investment.[6] In contrast, the present paper considers the effects of downstream competition and also changes in consumer surplus resulting from investment and competition.

The paper proceeds as follows. Section I sets up the model, using a framework and notation similar to Katz and Shapiro (1987). Section II formally discusses the two motives for investment mentioned earlier and explicitly considers the effect of a regulated access regime on these motives. The equilibrium of the resulting investment provision game is then examined and the optimal access pricing formula derived. Remaining sections discuss the use of alternative valuation methods (i.e., based on historical cost) in the optimal regulated price, the effect of asymmetries on firm size and profitability and constraints imposed on usage charges in two part tariffs. A final section concludes.

I. Model Set-Up

The analysis focuses on the provision of a single infrastructure investment. The infrastructure, when built, is not capacity constrained and, for simplicity, can be operated at zero

[6] The Gans and Williams (1999) model was constructed for the Australian context where many access issues – particularly in transportation – arise between competitors in perfectly competitive world commodity markets. In that context, their non-rival assumption is appropriate. Nonetheless, the fully distributed costs outcomes are similar to the present paper as are the statements regarding asset valuation. The key difference is that, with downstream competition, pre-emption incentives play a critical role in matching private and social returns.

marginal cost. An example of this could be a new broadband telecommunications network; at the heart of many recent access issues (Laffont and Tirole, 1999).

The regulatory environment envisaged here is one where, once the infrastructure is built, the access seeker is entitled to access on terms that are set at that time.[7] The timeline of the model is depicted in Figure One. It is assumed that the regulator mandates access, so there is no issue of foreclosure or denial of access after the infrastructure is constructed and there is no uncertainty regarding access terms.[8] To this end, before the investment takes place, the regulator commits to a *pricing formula* that relates information gathered at the time access is sought to a particular pricing outcome. This formulaic approach is common to most regulatory settings that relate cost and demand parameters to prices.[9] As will be demonstrated here, the formula itself plays a critical role in encouraging optimal investment timing. This is because particular methods of valuing investment costs vary over time and, consequently, impact on the incentives of the both the access provider and seeker in their respective timing choices.

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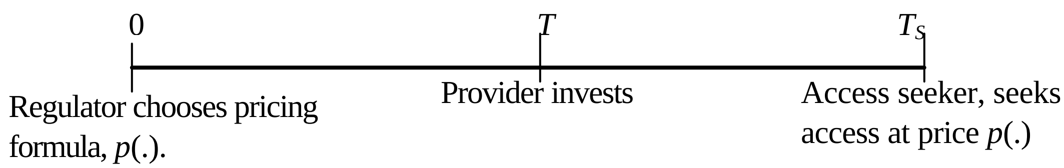
[7] This type of access regime is very common in rail and telecommunications. For example, in Australia, many jurisdictions have 'declared' key pieces of infrastructure giving seekers a right to access and have set out default pricing formulae that will apply in the case of a dispute of pricing. See King and Maddock (1996) and Gans and Williams (1999) for a discussion.

[8] In reality, even under regulated access regimes issues regarding non-price discrimination and foreclosure can arise. For a review of these issues in the context of telecommunications see Mandy (2000).

[9] It is rare of a regulatory regime to simply specify a price without providing guidelines as to how it will be adjusted to reflect changes in costs or demand. Thus, most regulatory pricing regimes are commitments to guidelines that describe how particular prices will be adjusted depending on available information.

Figure One: Model Timeline



Initially, it is assumed that regulated usage charges are given so as to concentrate on the regulator's choice of a fixed access charge, *p*(.).[10] This may involve losses for the infrastructure owner upstream but for the moment the notation for such losses is suppressed.[11] The issue of the optimal usage charge is revisited in Section V. Finally, for expositional simplicity, attention is restricted to charges incurred only in the time period access is initially sought.

The only choice regarding the infrastructure is over *when* it is built, if at all. In effect, the investment is constructed within a single time period. This assumption makes the timing decision an irreversible one, with infrastructure providers having no ability to 'scale-up' their investment over time.[12] From a strategic viewpoint, this limits our attention to infrastructure investments where a first-mover advantage in starting such investments is strong. In contrast, one can imagine situations – such as the construction of a completely new telecommunications network – where a provider may begin constructing that network but not complete it if it becomes convinced that a rival will dominate the market first. Many of the effects that arise in the

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[10] This fixed charge will be a function of timing choices of the access provider and seeker. To economise on notation, however, I will omit that functional notation except where necessary.

[11] As will be argued below, when there is imperfect competition downstream, it may be socially desirable to set usage charges below marginal cost (in this case zero). However, feasibility will constrain the usage charge to be above a certain level (see Section V).

[12] This is a common assumption for models that focus on pre-emption incentives. See Fudenberg and Tirole (1985), Katz and Shapiro (1987), and Riordan (1992).

discussion below would apply to situations where first-mover advantages are weaker but would add complications associated with the nature of competitive dynamics in the investment stage.[13] Thus, to simplify matters, as the focus here is on the regulator's role in manipulating pre-emption incentives, the instantaneous investment assumption is retained through this paper.

In their timing choice, investors trade off the value they receive from use of the facility with technological progress that reduces the cost of providing the infrastructure in later periods. Following Katz and Shapiro (1987), I assume time periods have length Δ and explore continuous time solutions as Δ approaches 0. In each time period, each firm in the industry decides whether to invest or wait. Once investment has taken place, the infrastructure appears immediately. If a firm invests at date *T*, the current cost of investment is simply $F(T)e^{rT}$, where *r* is the interest rate and *F*(*T*) is the present value, viewed from time 0 of investment expenses.

As mentioned above, the costs of infrastructure investment decline due to technical progress, i.e., $d(F(T)e^{rT})/dT < 0$ and $d^2(F(T)e^{rT})/dT^2 > 0$. Let F be the limit of current investment costs as T approaches infinity and F_0 be the cost of investment at time 0. On occasion I shall consider a particular functional form $F(T) = F_0 e^{-lT}$, so that investment costs decline exponentially. It is assumed that $l > r$, so as to be consistent with my earlier assumptions. In addition, I shall assume that the asset does not deteriorate over time. This simplifying assumption allows us to avoid the issue of re-investment and maintenance incentives.

To fix ideas, I will first consider the symmetric duopoly case. Define the following present discounted values:

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[13] See, for example, Reinganum (1989) and Tirole (1988) for a discussion of models of wars of attrition,

- p^d : duopoly profits if no investment takes place;
- Π^m : monopoly profits if a firm has exclusive access to infrastructure;[14]
- 0: profits if the rival firm has exclusive access;
- Π^d : duopoly profits if both firms have access to infrastructure.[15]

The following natural relationship is assumed to hold between these payoffs:

$$\Pi^m \geq 2\Pi^d > 0 \text{ and } \Pi^m \geq 2p^d \geq 0 .$$

It is, therefore, possible that duopoly profits after investment has taken place are lower than prior duopoly profits. Consumer surplus under each of these market structures is as follows:

- s: consumer surplus if no investment takes place;
- S^m : consumer surplus if a firm has exclusive access to infrastructure;
- S^d : consumer surplus if both firms have access to infrastructure,

where it is assumed that,

$$S^d > S^m \geq s \text{ and } S^d + 2\Pi^d > S^m + \Pi^m \geq s + 2p^d \geq 0 .$$

Therefore, the infrastructure is socially valuable and achieves its optimum under a duopoly rather than monopoly.

What is the socially optimal investment timing in this context? Timing choices allow infrastructure to be used by firms but also to potentially supply new goods to consumers or reduce final goods prices. The social planner, therefore, chooses T to maximise $(s+2p^d)(1-e^{-rT})+(S^d+2\Pi^d)e^{-rT}-F(T)$ that satisfies the first order condition,

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whereby, multiple investors compete for dominance during a prolonged construction phase.

[14] That is, there are the profits a provider would earn if access to its infrastructure was neither mandated nor regulated.

[15] These profit levels are for a given usage charge. In Section V, as the usage charge changes, so too will

$r\left(S^d - s + 2(\Pi^d - p^d)\right) = -F'(T^{SO})e^{rT^{SO}}$. It is assumed that $S^d - s + 2(\Pi^d - p^d) > F$ so that T^{SO} is finite.

II. Motives for Investment

As mentioned in the introduction, there are two broad incentives guiding the investment decision – a direct and a strategic incentive. To consider the first, let T be the time an infrastructure investment is made and $T_S = T$ be the time at which access to that infrastructure is sought. A provider will earn a monopoly profit downstream from T to T_S; after which it will earn duopoly profits plus any access payment, p, it expects to receive. In this case, the return (as of time 0) to a provider investing at time T is:

$$W(T) = \int_0^T rp^d e^{-rt}dt + \int_T^{T_s} r\Pi^m e^{-rt}dt + \int_{T_s}^{\infty} r(\Pi^d + p)e^{-rt}dt - F(T)$$
$$= p^d(1-e^{-rT}) + \Pi^m(e^{-rT} - e^{-rT_s}) + (\Pi^d + p)e^{-rT_s} - F(T)$$

Let $\hat{T}$ be the value of T that maximises this function, taking into account the fact that T_S might be contingent on T. The first order condition for this maximisation problem is:

$$\left(\Pi^m - p^d\right)e^{-rT} + \tfrac{dT_S(\hat{T})}{dT}(\Pi^d + p - \Pi^m)e^{-rT_s} - \tfrac{1}{r}\tfrac{dp(T)}{dT}e^{-rT_S} = -F'(\hat{T})/r\,.$$

The left-hand side of this expression reflects each firm's willingness to pay incentive.[16] Indeed, if access is sought immediately (i.e., if $T = T_S$), as I will show it does under optimal regulation,

these profit levels.

[16] Katz and Shapiro (1987) refer to this as i's *stand-alone* incentive. While this might be natural in their context of research and development, here I prefer to use an alternative terminology that reflects the idea that both parties are using the investment. Below stand-alone will be defined to be the case where a firm invests in infrastructure for their own use only.

then this willingness to pay incentive becomes simply, $\Pi^d - p^d + p$. The higher is this amount, the earlier a firm is willing to provide the infrastructure.

The above paragraph involves an implicit assumption that the access seeker would be willing to pay p to the provider rather than shut down or duplicate the facility at a later date. Duplication gives the potential seeker a payoff of $\Pi^d e^{-rT} - F(T)$ if it invests at *T*. Let $\widehat{T}$ be the choice of T that maximises this function. Note that $\widehat{T} \geq \hat{T}$. This possibility imposes an upper bound on the access charge that the seeker will accept. That is, it must be the case that $p \leq \Pi^d$, but if $\Pi^d \geq F$ this upper bound is strengthened so that $(\Pi^d - p)e^{-r\hat{T}} \geq \Pi^d e^{-r\widehat{T}} - F(\widehat{T})$ or $p \leq F(\widehat{T})e^{r\hat{T}} + \Pi^d(1 - e^{r\hat{T} - r\widehat{T}})$. Unless otherwise stated, it is assumed that *p* lies below these upper bounds.

The second motive to build infrastructure earlier is a strategic one. Each firm might be concerned that the other firm might *pre-empt* them by investing first. The benefit to investing first at time *T* is given by *W*(*T*) above. However, if the rival firm invests first, that firm must be paid p. Suppose that access is sought as soon as the infrastructure is built (i.e., that $T = T_S$). Hence, if a firm expects to be charged an access price of *p*, its payoff, in the event that it does not invest first, is:

$$L(T) = (1 - e^{-rT})p^d + \left(\Pi^d - p\right)e^{-rT},$$

where T is now the time that access is provided and sought. If both firms choose to invest at the same time, then I assume that the investor is determined by a coin toss so that each firm earns $\frac{1}{2}\left(W(T) + L(T)\right)$. Following Katz and Shapiro (1987), "a firm is willing to preempt at *T*" if $W(T) \geq L(T)$. Moreover, the assumptions on *F*(.) guarantee that the current pre-emption value, $\left(W(T)-L(T)\right)e^{rT}$, is increasing in T; that is, if it is worth pre-empting at some time, it is worth pre-empting at any time after that. With this in mind, the earliest pre-emption date, $\tilde{T}$, can be defined by $W(\tilde{T})=L(\tilde{T})$ or, alternatively, $2p=F(\tilde{T})e^{r\tilde{T}}$. Therefore, $2p$ is each firm's pre-emption motive for investment. Note that the motive for pre-emption comes from the difference between paying an access charge and having to pay an access charge. So even in the absence of symmetry the pre-emption date would be the same for both firms.

III. Equilibrium Investment and Regulation

I now turn to consider the equilibrium investment timing and how this depends on the choice of p. If firms seek access immediately, the earliest pre-emption date ($\tilde{T}$) is the same for both firms, while the assumption of symmetry means that their willingness-to-pay timing ($\hat{T}$) is identical. Given this, the investment date in any subgame perfect equilibrium is unique.

Proposition 1 (Equilibrium Timing). *Suppose that p(.) is such that access is always sought immediately (i.e., $T = T_S$). Then, equilibrium timing,* $T(p)=\min[\hat{T},\tilde{T}]$.

Using the observation that $W(\hat{T})\geq L(\tilde{T})$, this proposition follows from Katz and Shapiro (1987, p.408). Note that the symmetry assumption means that we cannot determine which firm will be the provider and which will be the seeker.

The important feature of this equilibrium is that investment timing is uniquely determined by the choice of pricing formula, p(.). The regulatory question becomes: what choice of p leads to $T(p)=T^{SO}$ and $T(p)=T_S$? The latter condition, that the seeker chooses to seek access immediately, encourages socially optimal use of the infrastructure and eliminates the social losses from monopoly. The value of seeking access at the date infrastructure is built is: $\left(\Pi^d - p\right)e^{-rT_S}$. So long as the derivative of this with respect to T_S is negative at the socially optimal timing choice, access will be sought immediately.[17]

The following proposition derives a pricing formula that implements the socially optimal investment timing and access seeking choices.

Proposition 2 (Optimal Regulated Price). *Assume that* $2\Pi^d - F(T^{SO})e^{rT^{SO}} \geq \max\left[2\Pi^d - 2F(\hat{T})e^{r\hat{T}}, 0\right]$. *Then the following regulated price:*

$$p(T_S) = r\tfrac{1}{2}(S^d - s) + r(\Pi^d - p^d) + \tfrac{1}{2}\left(1 + \tfrac{F'(T_S)}{F(T_S)}\right)F(T_S)e^{rT_S}$$

results in $T(p) = T^{SO}$ *and* $T_S = T^{SO}$.

The proposition is proved in the appendix. The condition in this proposition has an intuitive interpretation. It simply allows private investment and competition to be feasible. That is, industry profits when investment takes place at the socially optimal date are positive and exceed profits if each were to duplicate the facility.

How does the above formula serve to induce socially optimal timing and immediate competition? The first thing to observe is that regulation is able to achieve a first best outcome by manipulating the pre-emption incentives of market participants. If there were no strategic motive for investment, then it would be impossible to achieve a first best. This is because, under a privately funded system, the earliest date at which investment takes place would be determined by monopoly profits alone. This would necessarily be later than the socially optimal

[17] Of course, this assumes that the only method by which a seeker could achieve access is through a regulatory outcome. If a private solution can be negotiated, then the seeker and provider may prefer this to

date and would involve a period of muted competition. Because of pre-emption, it is possible to use strategic considerations to accelerate investment decisions. Indeed, without regulation, it is possible that investment may be accelerated too fast and investment might take place with an inferior technology. The goal of regulation is to use access-pricing expectations to align pre-emption incentives to be consistent with socially optimal decision-making.

While timing is important for an optimal outcome, also important is timely competition. That is, it must be optimal for the seeker to seek access to the infrastructure as soon as possible. The above pricing formula may be decreasing in T_S; the time access is sought. This can be easily seen using the functional form for $F(T) = F_0 e^{-lT}$. In this case,

$$p(T_S) = r\tfrac{1}{2}(S^d - s) + r(\Pi^d - p^d) + \tfrac{1}{2}(1 - l)F(T_S)e^{rT_S},$$

which is decreasing if $l = -F'(T)/F(T) < 1$. This may give the seeker an incentive to delay its access claims. However, because of the convexity of current costs in T, the seeker prefers to receive its payoff, $\Pi^d - p$, sooner rather than waiting for a lower access price that may have been significant if "spurts" in technological progress were permitted. Thus, access is sought immediately regardless of when provision takes place.

This means that a provider cannot expect a period of monopoly following provision. Instead it expects to receive a payoff of $\Pi^d + p(T) - F(T)e^{rT}$ at the time of investment. With this expectation, the above pricing formula manipulates pre-emption incentives by making it explicitly costly to provide infrastructure early and "strategically" costly to provide it late. As noted earlier, $p(T)$ is falling in T. This raises incentives to provide investment sooner rather than

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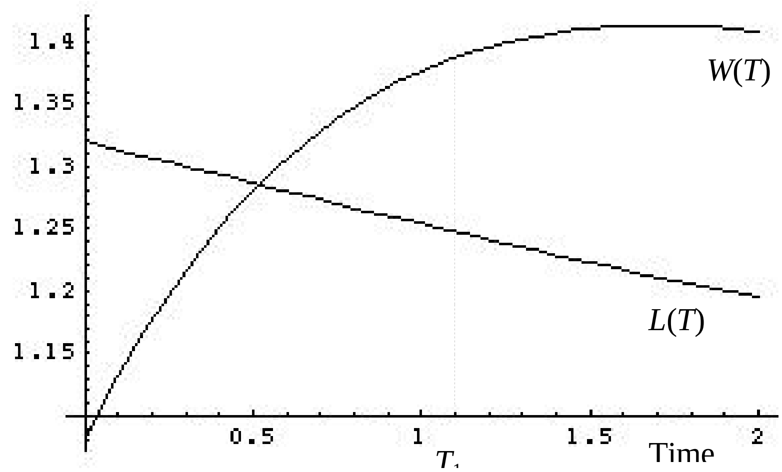
any regulated outcome (King and Maddock, 1999).

later. Thus, the gradient of $W(T)$ is steeper than it would otherwise be. However, by the same logic, the gradient of the seeker's payoff, $L(T)$, is less steep. The pricing formula ensures that these payoffs cross at a point where $W(T)$ is upward sloping. Thus, pre-emption timing always exceeds willingness-to-pay timing – providing infrastructure earlier than the crossing point is explicitly costly. This is depicted in Figure Two.

Figure Two: Equilibrium Under Optimal Regulation

($s = 1$, $S^d = 1.8$, $p^d = 1$, $\Pi^d = 1.7$, $r = 0.3$, $F(T) = e^{-0.9T}$, $T^{SO} \approx 0.5$)



The strategic costs of late provision are also demonstrated in that figure. Consider what happens if provision takes place at a point such as T_1. The payoff of the provider exceeds that of the seeker at that point. As such, the seeker reasons, that by providing themselves at time $T_1 - \Delta$, it receives $W(T_1 - \Delta)$ rather than $L(T_1)$. This reasoning is valid so long as $W(T_1) > L(T_1)$ and Δ is small. When $W(T_1) < L(T_1)$, the seeker does not have an incentive to pre-empt the provider. But this is not an equilibrium either because the provider can improve its payoff by investing later (as $W(T)$ is rising at any date before the socially optimal one).

The pricing formula is derived with this in mind – that is, that the equilibrium under the formula will be determined by pre-emption motives. As the key variable affected by timing is the (current) investment costs, for any given pricing formula, equilibrium timing $\tilde{T}$ will be determined by:

$$p(\tilde{T}) - F(\tilde{T})e^{r\tilde{T}} = -p(\tilde{T}) \text{ or } 2\,p(\tilde{T}) - F(\tilde{T})e^{r\tilde{T}} = 0 .$$

At this point, provider and seeker share equally in investment costs. The formula itself is one for which $\tilde{T} = T^{SO}$. Recall that T^{SO} is determined by the condition:

$$r(S^d - s) + r2(\Pi^d - p^d) + F'(T^{SO})e^{rT^{SO}} = 0 .$$

Therefore, the pricing formula is such that:

$$r(S^d - s) + r2(\Pi^d - p^d) + F'(\tilde{T})e^{r\tilde{T}} = 2\,p(\tilde{T}) - F(\tilde{T})e^{r\tilde{T}}$$

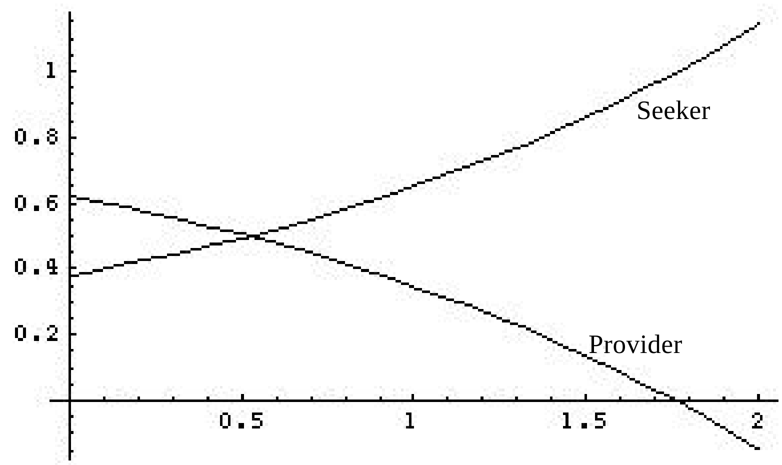
$$\text{or } p(T) = \underbrace{\tfrac{1}{2}\left(r\tfrac{1}{2}(S^d - s) + r(\Pi^d - p^d) + F'(T)e^{rT}\right)}_{\text{Marginal Social Cost of Delay}} + \underbrace{\tfrac{1}{2}F(T)e^{rT}}_{\text{Cost Share}} .$$

When investment takes place, the provider and seeker always share, equally, the investment cost at that point. In addition, the seeker pays the provider an amount equal to half the marginal social cost of delayed investment at that point. This payment is negative for investment that takes place before the socially optimal point and positive thereafter. Given the otherwise equal cost shares, firms compete for this additional payment, bidding it down to zero by investing at the socially optimal point.

An alternative way of considering this effect is by looking at the current cost shares that provider and seeker pay for each timing choice (see Figure Three). Notice that they share equally in the costs only at the socially optimal timing. The provider shares less in costs when it delays timing. However, competition between firms for this rent ensures that it is bid down to zero. So each firm shares equally in the costs at the socially optimal timing. That is, $p(T^{SO}) = \frac{1}{2} F(T^{SO}) e^{rT^{SO}}$. This is a natural implication of symmetry and the fact that the equilibrium is determined by the pre-emption motives that equalise the value of being a provider and seeker respectively. In the next section, pricing with asymmetric firms is explored. It is demonstrated that firms pay access charges that are proportional to their relative profitability in duopoly. The relationship between this pricing formula and fully distributed costs is left to the next section.

Figure Three: Cost Shares

($s = 1$, $S^d = 1.8$, $p^d = 1$, $\Pi^d = 1.7$, $r = 0.3$, $F(T) = e^{-0.9T}$, $T^{SO} \approx 0.5$)



This access pricing formula has important practical properties. First, recall that it determines the fixed charge in efficient two-part marginal cost pricing, with the per-unit charge potentially set optimally (see Section V). It is a once off charge paid at the time access is sought. Second, the charge can be determined at the time access is sought using information available at that time. The regulator *need only commit to the pricing formula* at time 0. It can then use realised timing choices and observables at that time to determine the actual charge. Given the efficiency of the price itself, the regulator has no incentive to renege on that commitment. The following example demonstrates how this can be achieved.

Example: *Let* $F(T) = e^{-lT}$. *Suppose that production takes place at a constant marginal cost. Prior to the infrastructure being available, this marginal cost is equal to 1 and after it is equal to c < 1. Inverse industry demand for a quantity of Q is* $P = Q^{-e}$ *where 0 < e < 1.* $Q = q_1 + q_2$, *the individual quantities of firms 1 and 2, respectively. Duopoly competition is Cournot. It is assumed here that the usage charge is 0.*[18] *So, in equilibrium:*

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[18] This assumption is relaxed in Section V.

$$q_1 = q_2 = \left(\tfrac{1}{c2^{1+e}}(2-e)\right)^{\frac{1}{e}},\ p^d = \left(\tfrac{1}{2^{1+e}}(2-e)\right)^{\frac{1}{e}}\left(\tfrac{e}{2-e}\right)\ and\ \Pi^d = \left(\tfrac{1}{c2^{1+e}}(2-e)\right)^{\frac{1}{e}} c\left(\tfrac{e}{2-e}\right)$$

while

$$s = \tfrac{4}{1-e}\left(\tfrac{1}{2^{1+e}}(2-e)\right)^{\frac{1}{e}}\ and\ S^d = \tfrac{4c^2}{1-e}\left(\tfrac{1}{c2^{1+e}}(2-e)\right)^{\frac{1}{e}}.$$

When access is sought, at T_S, the regulator computes the price as follows. It takes the current (replacement) cost of the infrastructure at that time, $e^{-(l-r)T_S}$ and puts it into the formula to determine the price:

$$p(T_S) = r\left(\tfrac{1}{2^{1+e}}(2-e)\right)^{\frac{1}{e}}\left(\tfrac{2}{1-e}\left(c^{2-1/e}-1\right)+\left(\tfrac{e}{2-e}\right)\left(c^{1-1/e}-1\right)\right)+\tfrac{1}{2}(1-l)e^{-(l-r)T_S}.$$

Therefore, the regulator needs only to compile information regarding elasticity of demand, e, marginal cost differentials, technological progress, interest rates and the (replacement) cost of the infrastructure to compute the fixed charge.

While the informational requirements appear to be demanding, they are no more demanding than any regulated price outcome that requires cost and demand side information. This analysis is designed to demonstrate what the optimal price should be. Adding informational problems that have been the concern of much regulatory analysis is the next step and beyond the scope of this paper.

Before turning to relax two key assumptions – symmetry and feasibility – it is worth reflecting upon the regulatory processes at work here. The current model envisages a regulator announcing (at date 0) this pricing formula and implementing it when access is sought. However, in many countries essential facility regulation is triggered as the result of a failure of unregulated access negotiations.[19] In this case, regulation is an outside option in such negotiations. In the absence of the regulatory outside options, even under efficient (Nash or cooperative) bargaining, infrastructure costs are sunk and hence, are not part of those negotiations.[20] The expected access price, while still being a two-part tariff, would not be

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[19] In Australia, this mechanism is explicitly codified (King and Maddock, 1999). In other countries, this is how the process appears to work in practice.

[20] An exception would be some sort of joint venture in which access negotiations took place prior to actual

contingent on infrastructure costs. As such, the actual charge would be independent of timing. Even if access were allowed and constructed in a way to allow for competition, investment timing is unlikely to be socially optimal (Gans and Williams, 1999).

The regulatory outside option can modify the nature of access negotiations, even if regulation is not explicitly exercised. Gans and Williams (1999) demonstrate that, under Rubinstein-style bargaining, the regulatory option always binds and hence, firms will expect this price in negotiations. As the regulated price can be structured to depend on investment costs, it will influence investment-timing choices. Hence, even if regulation is triggered after failed negotiations, it can aid in aligning the equilibrium in the investment game to socially optimal outcomes. It should be noted, however, that the model of Gans and Williams (1999) did not involve competing firms and one would have to examine the possibility of foreclosure issues in private access negotiations to be assured that regulation by negotiation would work.[21]

Nonetheless, it is worth pointing out that the regulatory price formula need not be based on the *replacement cost* of the infrastructure at the time access is sought. It could be based on *historical cost* with a discount to take into account any delay between investment timing and the time access is sought.[22] The difference between the two methods is that the replacement cost depends critically on the costs of investing at the time access is sought while historical costs depend critically on the costs actually incurred by the provider. That is, if infrastructure is provided at time, T, and access is sought at $T_S = T$, then current replacement cost at T_S, is $F(T_S)e^{rT_S}$ while historical cost is $F(T)e^{rT}$. Because of technological progress, historical cost

investment.

[21] See Rey and Tirole (1996) and King and Maddock (1997).

will generally exceed replacement cost. However, as is demonstrated below, if the access pricing formula creates an incentive for access to be sought as soon as possible, both asset valuation methods will be identical. The key issue, therefore, is whether a historical cost methodology creates the incentive for timely access seeking that is provided by replacement cost (see Proposition 2).[23]

The following proposition demonstrates that when the access charge is based on historical cost, the socially optimal outcome is implemented.[24]

Proposition 3 (Optimal Regulated Price, Historical Cost). *Assume that* $2\Pi^d - F(T^{SO})e^{rT^{SO}} \geq \max\left[2\Pi^d - 2F(\hat{T})e^{r\hat{T}}, 0\right]$. *Then the following regulated price:*

$$p(T) = r\tfrac{1}{2}(S^d - s) + r(\Pi^d - p^d) + \tfrac{1}{2}\left(1 + \tfrac{F'(T)}{F(T)}\right)F(T)e^{rT},$$

where T is the time investment takes place, results in $T(p) = T^{SO}$ *and* $T_S = T^{SO}$.

Once again the proof of the proposition is in the appendix. Effectively, historical cost and replacement cost methods of asset valuation collapse to the same thing when $T_S = T$, i.e., access is sought immediately. However, while under replacement cost the seeker chose $T_S = T$ perhaps despite the fact that the access charge may be falling over time, here it does so because waiting carries no benefit in terms of a falling price. As Π^d always exceeds *p*, it is worth seeking access as soon as possible.

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[22] King (1996) provides a discussion of issues of asset valuation in access regulation environments.
[23] Gans and Williams (1999) contains an extensive discussion of the potential differences in incentives provided by replacement and historical cost methodologies in access settings.
[24] A similar equivalence is demonstrated in Gans and Williams (1999).

IV. Firm Asymmetries

The results above do not depend on symmetry. To see this, suppose that one firm (firm 1) is larger, more profitable or more efficient, than the other (firm 2). That is, $p_1^d > p_2^d$, $\Pi_1^d > \Pi_2^d$ and $\Pi_1^m > \Pi_2^m$. Consumer surplus is assumed to remain as before with:

$$S^d + \Pi_1^d + \Pi_2^d > s + p_1^d + p_2^d \text{ and } S^d + \Pi_1^d + \Pi_2^d > S^m + \Pi_1^m + \Pi_2^m .$$

The costs of investment are the same for both firms. Thus, so long as both firms have access to the investment, the regulator still need not be concerned about which firm actually undertakes the investment.[25]

These asymmetries now mean that firms have different willingness-to-pay. In general, $\hat{T}_1 < \hat{T}_2$.[26] However, the earliest pre-emption date is identical for both firms, as the identity of the winner does not alter industry profits.[27] That is, suppose that the access price paid by firm i is p_i. Then, for all i, $p_1 + p_2 = F(\tilde{T}_i)e^{r\tilde{T}_i}$, so $\tilde{T}_1 = \tilde{T}_2 = \tilde{T}$. Each firm's motive for pre-emption is to avoid paying an access charge and to receive an access payment from the other. With these observations, the subgame perfect equilibria in the investment timing game are summarised in the following proposition.

Proposition 4 (Equilibrium Timing). *Suppose that p_1 and p_2 are such that access is always sought immediately. Then, equilibrium timing, $T(p) = \min[\hat{T}_1, \tilde{T}]$. If $\hat{T}_1 < \hat{T}_2 < \tilde{T}$, there is a second equilibrium in which 2 invests at $\hat{T}_2$ if and only if $W_1(\hat{T}_1) \leq L_1(\hat{T}_2)$.*

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[25] In reality, the costs of investing may differ between firms and create an issue as to which firm invests first. However, the general results here will continue to apply although it is likely some amendment will be necessary to ensure that investment costs are at a minimum. This amended model is left for future research.

[26] If the access charge levied on firm 2 is low relative to that on 1, this inequality could be reversed.

[27] A similar result arises in the innovation licensing literature (Gans and Stern, 2000).

This proposition is proven by Katz and Shapiro (1987, p.410). Note that it is possible that the smaller firm 2 could be the provider. Indeed, even where it would never be profitable for that firm to invest as a stand-alone entity, i.e., $\Pi_2^m < F$,[28] it could be profitable for them to invest as a provider of access so long as $\Pi_1^d + \Pi_2^d > F$. Thus, where a natural monopoly technology is concerned, being small is no constraint. Hence, despite the asymmetries in profitability, competition can be created between market participants.

In using the regulated access price to create competition for infrastructure provision, it is possible that the previous access price could be used. The problem is that while that charge is surely lower than Π_1^d, it may exceed Π_2^d even though private provision under competition is feasible, i.e., $\Pi_1^d + \Pi_2^d \geq F(T^{SO})e^{rT^{SO}}$. Fortunately, there is some flexibility as to the form of the access price. It is possible to construct an optimal access regime so that firm 1 pays a charge that exceeds firm 2, i.e., $p_1(T) > p_2(T)$. This is because, in order to align pre-emption timing with the social optimum, the sum of access charges must satisfy the following condition:

$$p_1(\tilde{T}) + p_2(\tilde{T}) = r\left(S^d - s + \Pi_1^d - p_1^d + \Pi_2^d - p_2^d\right) + \left(1 + \tfrac{F'(\tilde{T})}{F(\tilde{T})}\right)F(\tilde{T})e^{r\tilde{T}}.$$

This gives the regulator considerable choice as to the formula determining the actual price that will be charged to a given firm.

What criteria should be used to select among alternative charges? It is possible for one type of firm to be charged too much so that $\Pi_i^d < p_i$. This is important as effective competition relies on charges being feasible at times before T^{SO}. To ensure that access charges are payable by both firms we can assign weights a_i to each firm so that:

[28] Recall that F is the limit on investment costs as time goes on.

$$p_i(\tilde{T}) = a_i r\left(S^d - s + \Pi_1^d - p_1^{\,d} + \Pi_2^d - p_2^{\,d}\right) + a_i\left(1 + \tfrac{F'(\tilde{T})}{F(\tilde{T})}\right)F(\tilde{T})e^{r\tilde{T}} \text{ for all } i,$$

with $a_1 + a_2 = 1$. For both $\Pi_1^d \geq p_1$ and $\Pi_2^d \geq p_2$ to be satisfied,

$$a_1 = \frac{\Pi_1^d}{\Pi_1^d + \Pi_2^d} \text{ and } a_2 = \frac{\Pi_2^d}{\Pi_1^d + \Pi_2^d}.$$

Each firm pays a share in proportion to the profits they make in duopoly. In equilibrium, each firm ends up sharing in investments costs according to the same weights, a_i.

This method of cost allocation is similar to a fully distributed cost methodology. Indeed, in equilibrium, it is equivalent to this. However, the rationale behind the allocation is solely to encourage the maximum of competition in infrastructure provision. That is, the shares are set so as to make it possible for both firms to be able to pay their respective charges whenever private investment is feasible, i.e., $\Pi_1^d + \Pi_2^d \geq F(T^{SO})e^{rT^{SO}}$ implies $\Pi_i^d \geq p_i$ for all *i*.

V. Optimal Usage Charges

In the previous sections, the usage component of the regulated access pricing regime was taken as given. Indeed, for notational ease, it has been assumed equal to upstream marginal cost (of zero); eliminating any upstream rents or costs associated with access. Nonetheless, all of the previous literature on access pricing has been concerned with this issue. In particular, for the complete information environment of this paper, it has been argued that the optimal usage charge should be set below upstream marginal cost to counter the effects of imperfect competition downstream (Armstrong, Doyle and Vickers, 1996).

This issue is relevant here in so far as feasibility requirement is concerned – that it is privately profitable to invest at the socially optimal time rather than delay or duplicate the facility or not invest at all. If downstream profits are insufficient for this requirement to be met, then a usage charge below marginal cost designed to lower final good prices may be undesirable. It may be better to lift the usage charge and allow some downstream profits, so that the industry as a whole breaks even.

To see this, let a be the regulated usage charge. Note that when this does not equal upstream marginal cost, even if they are otherwise symmetric, the usage charge impacts of the access provider and seeker's downstream profits in different ways. For the seeker, its downstream profits (gross any fixed access charge) are decreasing in a. That is, $\partial \Pi_S^d(a)/\partial a < 0$. On the other hand, the provider always sets the transfer price to its downstream unit equal to its upstream marginal cost. So an increase in a, softens competition downstream and raises its profits.[29] That is, $\partial \Pi_P^d(a)/\partial a > 0$ for all a. Finally, consumer surplus (S^d) also now depends negatively on a.

For a given a, the earliest pre-emption date, $\tilde{T}$, is now defined by:

$$\Pi_P^d(a) - \Pi_S^d(a) + 2p = F(\tilde{T})e^{r\tilde{T}}.$$

This means that the socially optimal fixed charge should equal:

$$p(T_S) = r\tfrac{1}{2}(S^d(a) - s) + \tfrac{1}{2}((1-r)\Pi_P^d(a) - rp^d) + \tfrac{1}{2}((1+r)\Pi_S^d(a) - rp^d) + \tfrac{1}{2}\left(1 + \tfrac{F'(T_S)}{F(T_S)}\right)F(T_S)e^{rT_S}$$

Note that this charge is higher (lower) than that derived in Section III if $a < (>)\ 0$. Thus, in principle, the regulator can choose a usage charge to maximise ex post surplus. However, in so

[29] It would optimally charge another firm a usage charge greater than marginal costs to raise industry profits

doing, it must be recognised that the optimal fixed charge would have to be adjusted to reflect any rents created or losses imposed on the infrastructure owner.

In a homogenous products industry, the optimal usage charge will typically involve zero profits being earned downstream. Consequently, this may conflict with the feasibility requirement. This requirement will impose a lower bound on a so that the feasibility requirement is just met. From an industry-wide perspective, this represents an implementation of Ramsey or average cost pricing downstream; where average costs include the sunk costs of investment upstream.[30] Nonetheless, this highlights the fact that because usage charges affect the distribution of industry rents as well as their overall size, it must be taken into account when setting regulated fixed charges.

VI. Conclusion

This paper has demonstrated how appropriate regulated access pricing can be used to induce a competition between rivals in an industry to provide infrastructure. In equilibrium, investment takes place at the socially optimal time despite being accompanied by competition and there being no government subsidies. As such, it has been demonstrated how regulation can practically resolve trade-offs between investment incentives and competition to elicit the optimal provision and use of essential facilities. In so doing, it provides a rationale, based on investment incentives, for determining levels of fixed charges in two-part pricing regimes.

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downstream.

[30] An alternative would be to grant the provider with a temporary monopoly; imposing the socially optimal usage charge at a later time. However, with concave social surplus, it will be better to satisfy feasibility requirements by constraining the usage charge than by granting the provider a temporary monopoly

Nonetheless, the analysis is really only a beginning. First, issues of asymmetric information were set aside completely. This paper was designed to identify optimal pricing under ideal conditions. As with static regulation issues, this analysis can be built upon to consider situations in which costs and profits were not observable.[31] Second, issues regarding the choice of capacity of the infrastructure were not dealt with. The infrastructure had a limitless capacity and did not depreciate. However, by restricting capacity a provider could potentially influence access pricing. Finally, infrastructure investment is inherently uncertain. As such, if providers bear risk when investing, they must be compensated for this risk if they are to invest in a socially optimal manner. In real applications, the proposed pricing formula will need to be adjusted to compensate providers for such costs (Hausman, 1997). Future research may be able to consider what form optimal pricing would take under such conditions.

Finally, a critical assumption that drives the above analysis is feasibility, i.e., $2\Pi^d \geq e^{rT^{SO}} F(T^{SO})$. This assumption allows competition to drive infrastructure investment without the need for government subsidisation. However, in some situations, duopolistic competition might be so intense that both private provision and immediate competition might not be possible.[32] This could mean that access regimes that granted access to all potential entrants would not be workable as the requisite level of duopoly rents would not remain following the

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downstream.

[31] Incomplete information would affect both the regulatory price as well as the behaviour of the firms involved as the pricing formula derived here assumes those firms have complete information regarding each other's profits and costs. Given the 'bidding' structure of the model used here it may be possible to utilise results from auction theory to explore such issues. However, this is an extension beyond the scope of the current paper.

[32] This condition will certainly become important when entry is possible. Entry will tend to dissipate future industry rents and hence, the interaction between access pricing to encourage entry without harming investment incentives remains an open issue.

investment. One could imagine that such considerations would entail placing a floor on the potential access charge so as to guarantee that private investment is feasible. Future research could profitably explore what happens to the optimal access regime when the feasibility assumption is not satisfied. Indeed, by so doing, some links may be drawn with patent policy literature. The rationale behind patents includes the notion that profits are completely dissipated without the monopoly protection a patent affords. However, for some inventions this is not the case and some form of compulsory licensing regime might be socially optimal (von Hippel, 1988).

Appendix

Proof of Proposition 2

To prove this proposition it is useful to first prove the following lemmas.

Lemma 1. *$p(T_S)$ is equal to $\frac{1}{2}F(T)e^{rT}$ at $T_S = T^{SO}$.*

PROOF: Observe that when $T_S = T^{SO}$, that, by the first order conditions determining the choice of T^{SO},

$$p = -\tfrac{1}{2}F'(T^{SO})e^{rT^{SO}} + \tfrac{1}{2}\left(1+\tfrac{F'(T^{SO})}{F(T^{SO})}\right)F(T^{SO})e^{rT^{SO}} = \tfrac{1}{2}F(T^{SO})e^{rT^{SO}}.$$

Lemma 2. *Let $T_S = T$. Then, with the pricing rule of Proposition 2, the provider's willingness-to-pay timing, $\hat{T} \geq T^{SO}$.*

PROOF: Assume that $T_S = T$. Under the above pricing rule,

$$W(T) = p^d(1-e^{-rT}) + (\Pi^d + p(T))e^{-rT} - F(T).$$

To find $\hat{T}$, this function is maximised yielding the first order condition:

$$-r(\Pi^d - p^d + p(T))e^{-rT} + \tfrac{\partial p(T)}{\partial T}e^{-rT} - F'(T) = 0,$$

Substituting $\partial p/\partial T$ from lemma 1 and rearranging we have:

$$W'(T) = -r(\Pi^d - p^d + r\tfrac{1}{2}(S^d - s^d) + r(\Pi^d - p^d))e^{-rT} + \tfrac{1}{2}(F''(T) - F'(T)).$$

We wish to check whether this is positive at $T = T^{SO}$. Using the first order condition for the social planners problem, we have:

$$W'(T^{SO}) = -r(\Pi^d - p^d)e^{-rT^{SO}} - \tfrac{1}{2}(1-r)F'(T^{SO}) + \tfrac{1}{2}F''(T^{SO}).$$

At T^{SO}, this expression must be non-negative (as $-r(\Pi^d - p^d)e^{-rT^{SO}} \geq F'(T^{SO})$), meaning that $W'(T^{SO}) \geq 0$. Hence, $\hat{T} \geq T^{SO}$.

Lemma 3 *Suppose that the infrastructure is provided at date,* $T_P \leq T^{SO}$. *Then, with the pricing rule of Proposition 2, the seeker's payoff at* T_P, $e^{-rT_S}\left(\Pi^d - p(T_S)\right)$, *is non-increasing in* T_S.

PROOF: Note that

$$\frac{\partial\, e^{-rT_S}\left(\Pi^d - p(T_S)\right)}{\partial T_S} = -r\left(\Pi^d - p(T_S)\right)e^{-rT_S} - \frac{\partial\, p(T_S)}{\partial T_S}e^{-rT_S}.$$

This expression is less than zero if the following inequality holds:

$$r(\Pi^d - p) \geq -\tfrac{dp}{dT_S} \qquad (*)$$

The right hand side of (*) is: $-\tfrac{1}{2}e^{rT_S}\left(rF(T_S)+(1+r)\,F'(T_S)+F''(T_S)\right)$. Note that:

$$\begin{aligned} rF(T_S)+(1+r)F'(T_S)+F''(T_S) &\geq rF(T_S)+(1+r)F'(T_S)-rF'(T_S) \text{ (by } -F''(T)\leq rF'(T)\text{)} \\ &= rF(T_S)+F'(T_S) \end{aligned}$$

This implies that

$$-\tfrac{1}{2}e^{rT_S}\left(rF(T_S)+(1+r)\,F'(T_S)+F''(T_S)\right) \leq -\tfrac{1}{2}e^{rT_S}\left(rF(T_S)+F'(T_S)\right)$$

Substituting this into (*) we have:

$$\begin{aligned} & r(\Pi^d - p)+\tfrac{dp}{dT_S} \\ &= r(\Pi^d - \tfrac{1}{2}F(T_S)e^{rT_S}) + \tfrac{1}{2}e^{rT_S}\left(rF(T_S)+F'(T_S)\right) \\ &= r\Pi^d - \tfrac{1}{2}e^{rT_S}F'(T_S) \\ &\geq r\Pi^d + r\tfrac{1}{2}e^{rT_S}F(T_S) \text{ (by } rF(T)\leq -F'(T)\text{)} \end{aligned}$$

This last expression is clearly positive proving the lemma.

With this we need only to check that the seeker does not choose to wait and duplicate the asset. A sufficient condition for this to be the case would be if

$$e^{-rT^{SO}}\Pi^d - p(T^{SO}) = e^{-rT^{SO}}\Pi^d - \tfrac{1}{2}F(T^{SO}) \geq e^{-r\hat{T}}\Pi^d - F(\hat{T})$$

which follows from the feasibility assumption that $2\Pi^d - F(T^{SO})e^{rT^{SO}} \geq \max\left[2\Pi^d - 2F(\hat{T})e^{r\hat{T}}, 0\right]$.

Lemma 3 implies that the regulated price can be paid by the seeker as its payoff at T^{SO} is positive, by the feasibility condition in the proposition, and non-increasing up to that point. This means that access will be sought immediately for any investment taking place prior to T^{SO}, i.e., $T_S = T$. The provider will anticipate this and also know that it will not have any period of monopoly earnings.

By Lemma 2, $\hat{T} \geq T^{SO}$, so that in an optimal regulatory regime, $T(p) = \tilde{T}$. That is, we want the pricing rule to be such that pre-emption timing to equal the socially optimal timing. Using the first order condition for socially optimal timing and the pre-emption condition, this will occur so long as:

$$r\left(S^d - s^d + 2(\Pi^d - p^d)\right) + F'(T)e^{rT} = 2p - F(T)e^{rT}$$

$$\Rightarrow p = r\tfrac{1}{2}(S^d - s^d) + r(\Pi^d - p^d) + \tfrac{1}{2}\left(1 + \tfrac{F'(T)}{F(T)}\right)F(T)e^{rT}.$$

This is optimal so long as $\tilde{T} = T_S$. Therefore, suppose that p is determined by the date of seeker timing and can be manipulated by it. Then we have,

$$p = r\tfrac{1}{2}(S^d - s^d) + r(\Pi^d - p^d) + \tfrac{1}{2}\left(1 + \tfrac{F'(T_S)}{F(T_S)}\right)F(T_S)e^{rT_S},$$

the formula in the proposition.

Proof of Proposition 3:

The proof of Proposition 3 essentially follows that of Proposition 2. However, lemma 3 is unnecessary as, under historical cost, $p(T_S)$ is constant in T_S.

References

Armstrong, M., S. Cowan and J. Vickers (1994), *Regulatory Reform: Economic Analysis and British Experience*, MIT Press: Cambridge (MA).

Armstrong, M., C. Doyle and J. Vickers (1996), "The Access Pricing Problem: A Synthesis," *Journal of Industrial Economics*, 44 (2), pp.131-150.

Baumol, W.J., M.F. Koehn and R.D. Willig, "How Arbitrary is "Arbitrary"? or, Toward the Deserved Demise of Full Cost Allocation," *Public Utilities Fortnightly*, 120 (5), p.16.

Baumol, W.J. and J.G. Sidak (1994), *Toward Competition in Local Telephony*, MIT Press, Cambridge (MA).

Dasgupta, P. and J.E. Stiglitz (1980), "Uncertainty, Industrial Structure, and the Speed of R&D," *Bell Journal of Economics*, 11 (1), pp.1-28.

de Fontenay, C. and J.S. Gans (2000), "Extending Market Power Through Vertical Integration," *mimeo.*, Melbourne Business School.

Demsetz, H. (1968), "Why Regulate Utilities?" *Journal of Law and Economics*, 11, pp.55-66.

Fudenberg, D. and J. Tirole (1985), "Preemption and Rent Equalization in the Adoption of New Technology," *Review of Economic Studies*, 52, pp.383-401.

Gans, J.S. and S. Stern (2000), "Incumbency and R&D Incentives: Licensing the Gale of Creative Destruction," *Journal of Economics and Management Strategy*, 9 (4), pp.485-511.

Gans, J.S. and P.L. Williams (1999), "Access Regulation and the Timing of Infrastructure Investment," *Economic Record*, 79 (229), pp.127-138.

Hart, O. and J. Tirole (1990), "Vertical Integration and Market Foreclosure," *Brookings Papers on Economic Activity, Microeconomics*, pp.205-286.

Hausman, J.A. (1997), "Valuing the Effect of Regulation on New Services in Telecommunications," *Brookings Papers on Economic Activity (Microeconomics)*, pp.1-38.

Katz, M.L. and C. Shapiro (1987), "R&D Rivalry with Licensing or Imitation," *American Economic Review*, 77 (3), pp.402-420.

King, S.P. (1996), "Asset Valuation and Access to Essential Facilities Under Part IIIA of the Trade Practices Act 1974 (Cth)," in M. Richardson (ed.), *Deregulation of Public Utilities: Current Issues and Perspectives*, Centre for Corporate Law and Securities Regulation, Melbourne, pp.94-116.

King, S.P. and R. Maddock (1996), *Unlocking the Infrastructure,* Allen & Unwin: Sydney.

King, S.P. and R. Maddock (1999), "Light-handed Regulation of Access in Australia: Negotiation with Arbitration," *Information Economics and Policy*, 11 (1), pp.1-22.

Laffont, J.-J. and J. Tirole (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press, Cambridge (MA).

Laffont, J.-J. and J. Tirole (1994), "Access Pricing and Competition," *European Economic Review*, 38, pp.1673-1710.

Laffont, J.-J. and J. Tirole (1999), *Competition in Telecommunications*, MIT Press: Cambridge (MA).

Mandy, D.M. (2000), "Killing the Goose That May Have Laid the Golden Egg: Only the Data Knows Whether Sabotage Pays," *Journal of Regulatory Economics*, 17 (2), pp.157-172.

Reinganum, J.F. (1989), "On the Timing of Innovation," in R. Schmalansee and R. Willig (eds.), *Handbook of Industrial Organization*, Vol.1, Elsevier, Amsterdam, pp.849-908.

Rey, P. and J. Tirole (1996), "A Primer on Foreclosure," *Handbook of Industrial Organization*, Vol.3, Elsevier, Amsterdam, (forthcoming).

Riordan, M.H. (1992), "Regulation and Preemptive Technology Adoption," *RAND Journal of Economics*, 23 (3), pp.334-349.

Tirole, J. (1988), *The Theory of Industrial Organization*, MIT Press: Cambridge (MA).

Vickers, J. (1995), "Competition and Regulation in Vertically Related Markets," *Review of Economic Studies*, 62 (1), pp.1-18.

Von Hippel, E. (1988), *The Sources of Innovation*, Oxford University Press: Oxford.