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Optimal Access Regulation with Downstream Competition

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Optimal Access Regulation with Downstream Competition*

Tina Kao, Flavio M. Menezes and John Quiggin

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Abstract

We analyse access price setting to a bottleneck facility where the facility owner also competes in the deregulated downstream market. We consider a continuum of market structures from Cournot to Bertrand. These market structures are fully characterised by a single parameter representing the intensity of competition. We first show how the efficient component pricing rule (ECPR) should be modified as the downstream competitive intensity changes. We then analyse the optimal access price where a total-surplus-maximizing regulator trades off production efficiency and pro-competitive effects.

JEL Classification L51

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1 Introduction

The reforms of the 1990s saw the unbundling of vertically integrated industries such as energy, telecommunications and rail. This entailed the introduction of competition where feasible, as in electricity generation, gas production, internet service provision, and long-distance telecommunications. In natural monopoly components of these industries, such as electricity and

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gas transmission and distribution, local loop in telecommunications and rail tracks, the preferred approach was the adoption of an access pricing rule. Accordingly, introducing competition in these segments has required regulators to define the terms and conditions of access to these "essential" network facilities and ensure that they are implemented. (See, for example, Joskow, 2007).

The need to inform regulatory decisions has led to a large literature on access pricing. See, for example, Armstrong (2002) for a survey. The standard stylized set-up involves two services. The first is the provision of a natural monopoly network (upstream) service, which is subject to price and entry regulation. The second (downstream) service is supplied by the incumbent and opened to potential competitors who require access to the network service. The literature has studied both regulated and deregulated downstream markets. With the former, the incumbent is assumed to be vertically integrated with its prices for both services regulated while the entrant acts as a price taker. (See, for example, Laffont and Tirole (2000) for the case of telecommunications and Armstrong (2002) for a review).

A particular focal point of the literature is the "Efficient Component Pricing Rule" (ECPR), which was initially proposed by Baumol (1983) and made popular by Baumol and Sidak (1994). Under the ECPR, the access price charged by a monopolist provider of an essential service is set at the monopolist's opportunity cost of providing the access, including any foregone revenue in the downstream market. Much of the literature on access pricing is concerned with understanding when the ECPR would be socially optimal and how the optimal access price would deviate from the ECPR. The seminal paper of Armstrong, Doyle, and Vickers (1996) examines the notion of ECPR and optimal access pricing under different assumptions including product differentiation, bypass and substitution possibilities. They concluded that if the break-even constraint for the incumbent does not bind, the optimal access price coincides with the ECPR provided that the opportunity cost is properly interpreted. When the break-even constraint binds in equilibrium, the optimal access price includes another Ramsey term, similar to the pricing rule in Laffont and Tirole (1994). Note that the optimality of the ECPR in this paper hinges on the fact that the regulator sets both upstream and downstream prices, and the assumption that the entrant cannot supply the entire demand at any reasonable prices. The latter assumption implies that the first best downstream pricing is equal to the incumbent's marginal cost.

With deregulated downstream (retail) price, Laffont and Tirole (1994) show that the ECPR holds as a first-best pricing rule only when a number of stringent assumptions hold. In particular, ECPR is optimal if the downstream market is characterized by Bertrand competition, where all goods are perfect substitutes. Economides and White (1995) conclude that the ECPR will generally be suboptimal when the downstream market price is above the relevant marginal cost. Economides and White examine the welfare effects of the ECPR under different market structures including monopoly, asymmetric Bertrand, and Cournot and show that less competitive market structures make the ECPR less desirable. With more market power, the social planner is able to accommodate a less efficient entrant by setting the access price below the level implied by the ECPR to improve welfare. With price taking entrants, Armstrong and Vickers (1998) and Armstrong and Sappington (2007) conclude that the optimal pricing can be above, below, or equal to marginal cost and, in general, will be below the ECPR.

In this paper we generalize previous work by allowing for the possibility of imperfectly competitive outcomes in downstream markets. In particular, the incumbent does not always have the power to set the retail price and the entrant can possess some market power. We do not, however, simply replace the standard assumption of Bertrand competition with the alternative of a Cournot duopoly. Rather, we consider a continuum of downstream market structures with Cournot and Bertrand as polar cases, and the intervening range representing different degrees of competitive intensity.

A natural way to model a continuum of downstream competitive intensity is to use the notion of competition in supply schedules. (See, for example, Grossman (1981), Robson (1981), Turnbull (1983), Klemperer and Meyer (1989), Grant and Quiggin (1996), Vives (2011), and Menezes and Quiggin (2011)). By considering families of more or less elastic supply schedules, it is possible to generate spaces of oligopoly games of which Bertrand and Cournot are polar cases. This approach allows us to parametrize the nature of competition in the downstream market.

We first analyze the relevant notion of the ECPR contingent on the degree of competitive intensity. The idea that the ECPR prices should be calculated based on post entry prices is close to the notion of M-ECPR proposed by Sidak and Spulber (1997). Our results complement those of Armstrong, Doyle, and Vickers (1996). We also impose a break-even constraint for the vertically integrated firm but unlike Armstrong, Doyle, and Vickers (1996), we assume that the regulator only regulates the access price, not the retail price. The removal of retail price caps has been a feature of nearly every regulatory regime in electricity, rail and telecommunications in developed countries.

In this setting we compare the socially optimal access price with the access price implied by the ECPR. With a regulated downstream price set to replicate the outcome of Bertrand competition, the access price may be set to maximize production efficiency. With a deregulated downstream price, however, the access price also affects allocative efficiency through the retail price. Thus, the optimal access price under downstream competition has to take into consideration both productive efficiency and downstream market power.

We show that, if the entrant is equally or more efficient, the regulator has an incentive to set the access charge below the marginal cost of providing access.[1] However, as the market becomes more competitive, the unconstrained optimal access charge approaches the marginal cost of providing access, and is equal to the marginal cost when the downstream market is perfectly competitive. As in Economides and White (1995), the optimal access price is less than the ECPR price when the market is not too competitive and is equal to the ECPR price when the market is sufficiently competitive; these statements will be made precise below.

If, however, the entrant is inefficient, the optimal access price could be above or below cost whereas the ECPR always deters inefficient entry.[2] For a less efficient entrant, in the limit, the optimal access price is always below

[1] We abstract from fixed costs for simplicity.

[2] In our model, the ECPR always sets prices greater than or equal to marginal cost since the incumbent firm can cease supplying the final product. We discuss this point further in Section 5.

cost.

Our framework allows us to provide a precise characterization of the optimality of the ECPR. In the absence of a break-even constraint and provided that the entrant is equally or more efficient, the ECPR is optimal in the limit as the downstream market approaches Bertrand competition. Taking the break-even constraint into consideration, constrained optimal access pricing coincides with the ECPR for a sufficiently competitive market structure. For a less efficient entrant, if the cost difference is small and if the market is not competitive, the regulator finds it welfare improving to accommodate inefficient entry by charging an access price less than the ECPR price. The trade-off between productive and allocative efficiency is in general complicated, and the optimal access price is not monotonic in the degree of competitive intensity in the final market.

2 The Setup

Consider a vertically integrated monopoly firm that produces a final good using one unit of a bottleneck service at marginal (unit) cost A and one unit of a firm specific input at cost c. The total marginal cost for the incumbent is $C_I = A + c$. A potential entrant needs access to the bottleneck facility to produce the final good. The entrant's marginal cost of producing the final product is $C_E = c_A + c_E$, where c_A denotes the regulated unit price of access to be paid to the incumbent, and c_E is the entrant's specific cost with the possibilities $c_E \lesseqqgtr c$. The specific costs are observable to firms and the regulator.

For simplicity only, the demand for the final goods is given by

$$P = a - Q \text{ where } a > A + \max\{c, c_E\}. \tag{1}$$

The timing is as follows. At $t = 0$ a total-surplus-maximising regulator sets the access price c_A. At period $t = 1$, knowing c_A, two firms compete in the final goods market. We allow firms to exit the final product market. However, the incumbent has to supply all the access demanded at the regulated price.

2.1 First-best outcome

The first best outcome would set $p = A + \min\{c, c_E\}$, so that $Q = a - A - \min\{c, c_E\}$. First best output in the absence of entry (and globally if $c_E \geq c$) is $Q^c = a - A - c$. Note that the monopoly output for the incumbent is $\frac{Q^c}{2}$, and that the welfare gain from the first-best without entry, relative to monopoly is $\frac{(Q^c)^2}{8}$.

3 Competition in supply schedules

We begin by considering the general case of a deterministic game in supply schedules. We show that, without loss of generality, we may confine attention to the case of linear supply schedules. We focus on the symmetric case where the strategy space for each firm consists of all linear supply schedules with a given slope β.

Definition 1 *A deterministic game in supply schedules with N players is determined by a demand function $D(P)$, (assumed linear for simplicity) a set of convex cost functions $c_i(q_i)$ and a family of supply functions $q_i(P, \theta_i)$ where q_i is continuously differentiable, convex, and increasing in both arguments, and $\theta_i \in [0,1], \forall i$ is the strategic variable for firm i.*

With this definition, the strategy space is $\Sigma = [0,1]^N$. We first observe

Lemma 1 *Under the stated conditions, there exists an equilibrium strategy vector $\Theta^* \in \Sigma$*

Proof. The market clearing price $P(\Theta)$ is the solution to

$$D(P) = \sum q_i(P, \theta_i)$$

and is decreasing in each of its arguments. The inverse demand facing firm i is

$$D_i(\Theta_{-i}, P) = D(P) - \sum_{j \neq i} q_j(P, \theta_j)$$

Hence, the best reply $\hat{\theta}_i(\Theta_{-i})$ maximizes

$$\Pi_i(\theta_i; \Theta_{-i}) = P(\Theta) q_i(P(\Theta), \theta_i) - c_i(q_i(P(\Theta), \theta_i))$$

Since $\Pi_i(\theta_i; \Theta_{-i})$ is a concave function, the best reply is unique, and hence, by the maximum theorem (Berge ..), $\hat{\Theta} : \Sigma \to \Sigma$, where $\hat{\Theta}_i(\Theta) = \hat{\theta}_i(\Theta_{-i})$ is a continuous self-mapping of a compact set on to itself. Hence, by Brouwer's fixed point theorem, $\hat{\Theta}$ has a fixed point $\hat{\Theta}^*$, which is an equilibrium strategy profile. ■

We now construct a game in linear supply schedules that is equivalent, in a neighborhood of equilibrium to a given game in arbitrary (differentiable, convex) supply schedules. For any Θ and define $\beta_i(\Theta), \gamma_i(\Theta)$ such that

$$\begin{aligned} \beta_i(\Theta) &= q_i'(P(\Theta), \theta_i) \\ \gamma_i(\Theta) + \hat{\beta}_i P(\Theta) &= q_i(P(\Theta), \theta_i) \end{aligned}$$

Further, let $P(\Gamma; B)$ be the solution to

$$D(P) = \sum (\gamma_i + \beta_i P)$$

We may then derive

Proposition 1 *If Θ^* is an equilibrium for the deterministic game in supply schedules given by $D(P), c_i(q_i), i = 1...n,$ and $q_i(P, \theta_i), i = 1..n,$ then $\Gamma^* = (\gamma_1(\Theta^*)...\gamma_N(\Theta^*))$ is an equilibrium for the deterministic game in supply schedules given by $D(P), c_i(q_i), i = 1...N,$ and $\tilde{q}_i(P, \gamma_i) = \gamma_i + \beta_i\left(\hat{\Theta}^*\right)P$*

Proof. Let $\tilde{\Pi}_i(\gamma_i; \Gamma_{-i}, B) = P(\gamma_i; \Gamma_{-i})(\gamma_i + \beta_i P(\gamma_i; \Gamma_{-i}, B)) - c_i(\hat{\gamma}_i + \beta_i P(\gamma_i; \Gamma_{-i}, B)).$ Then, in a neighborhood of $\Gamma(\Theta^*)$,

$$\tilde{\Pi}_i(\gamma_i(\Theta); \Gamma_{-i}(\Theta^*), B(\Theta^*)) \approx \Pi_i\left(\theta^*{}_i; \Theta^*_{-i}\right) \tag{2}$$

and

$$\frac{\partial \tilde{\Pi}_i}{\partial \gamma_i}\gamma_i'(\theta_i^*) \approx \frac{\partial \Pi_i}{\partial \theta_i}$$

In particular, if $\frac{\partial \Pi_i}{\partial \theta_i} = 0$, $\forall i$, then $\frac{\partial \tilde{\Pi}_i}{\partial \gamma_i} = 0$, $\forall i$.It follows that if Θ^* is an equilibrium strategy profile, so is Γ^*, as required. ■

The proof of Proposition 1 is simple, but it encapsulates an important, and often misunderstood, feature of Nash equilibrium in oligopoly games (and, for that matter, games in general). The best reply for firm i depends only on the residual demand curve determined by the market structure and the strategic choices of other firms, as perceived by i. Provided that the strategy space available to firm i is sufficient to allow any non-negative choice for q_i, it does not matter how that strategy space is represented by the firm. Firm i may be regard itself as picking a quantity q_i^*, the associated price P^* determined by the residual demand curve, or the strategic variable θ_i^* for a family of supply curves, such that $q_i(P^*, \theta_i^*) = q_i^*$.

Hence, assuming all firms are symmetric, there is no loss of generality in assuming that the strategy space for each firm consists of all linear supply schedules with a given slope β.

4 Downstream market equilibrium

To simplify subsequent algebra, following Menezes and Quiggin (2011), we specify the strategic choice for firm i as a choice of supply schedules, determined by the strategic variable $\alpha_i = \gamma_i + \frac{C_i}{2} + \beta C_i$, where $\gamma_i = q_i(0)$, as follows:

$$q_i = \max\left\{\alpha_i - \frac{C_i}{2} + \beta(P - C_i), 0\right\}, i = I, E, \tag{3}$$

where the strategic variable α_i is a scalar variable representing upward or downward shifts in supply and $\beta \geq 0$ is an exogenous parameter reflecting the intensity of competition.

The slope of the residual demand curve facing any given firm is determined by the slopes of the demand schedule and of the supply schedules of other firms. The parameter β may, therefore, be interpreted as representing the aggressiveness of competition in the market.[3]

With the normalization $\alpha_i = \gamma_i + \frac{C_i}{2} + \beta C_i$, the first-best symmetric case is given by $P = C_I = C_E = A + c$ and $\alpha_I = \alpha_E = a/2$.

Replacing the supply schedule (3) into the inverse demand curve (1), we obtain:

$$P = \frac{a - (\alpha_I + \alpha_E)}{1 + 2\beta} + \frac{(C_I + C_E)}{2}. \tag{4}$$

[3]The parameter β is given exogenously in this paper. It can be thought for example as being determined by some multi-stage game with the ealier stage outside of the model.

And we have

$$\begin{aligned} q_i &= \max\left\{\alpha_i - \frac{C_i}{2} + \beta\left(P - C_i\right), 0\right\} \\ &= \max\left\{\alpha_i - \frac{C_i}{2} + \beta\left(\frac{a - (\alpha_I + \alpha_E)}{1 + 2\beta}\right) + \beta\frac{(Cj - C_i)}{2}, 0\right\}. \end{aligned}$$

So

$$Q = (\alpha_I + \alpha_E) - \frac{(C_I + C_E)}{2} + 2\beta\left(\frac{a - (\alpha_I + \alpha_E)}{1 + 2\beta}\right)$$

for an interior solution.

The incumbent's profits comes from sales in the final goods market and sales in the intermediate good market:

$$\pi_I = (P - C_I)\, q_I + (c_A - A)\, q_E. \tag{5}$$

Maximising yields the incumbent's best reply function:

$$\alpha_I(\alpha_E) = \frac{2a - 2\alpha_E + (1 + 2\beta)\, C_E + 2\beta\,(1 + 2\beta)\,(A - c_A)}{4\,(1 + \beta)}. \tag{6}$$

For the potential entrant,

$$\pi_E = (P - C_E)\left(a - P - \left(\alpha_I - \frac{C_I}{2}\right) - \beta\,(P - C_I)\right). \tag{7}$$

Maximising yields:

$$\alpha_E(\alpha_I) = \frac{2a - 2\alpha_I + (1 + 2\beta)\, C_I}{4\,(1 + \beta)}. \tag{8}$$

Both best responses are downward sloping. If $c_A = A$, the two best responses are symmetric. For $c_A \neq A$, the incumbent realizes profit or loss in the input market and this affects its incentives in the final product market. In particular, as β increases, the entrant produces more for any given level of the incumbent's output. However, for $c_A > A$, as β increases, the incumbent may have incentive to decrease its output since selling the input to the entrant may be more profitable.

Solving the two best responses gives the interior solution:

$$\alpha_I^* = \frac{2a - C_I + 2C_E\,(1 + \beta) + 4\beta\,(A - c_A)\,(1 + \beta)}{4\beta + 6} \tag{9}$$

$$\alpha_E^* = \frac{2a - C_E + 2C_I\,(1 + \beta) - 2\beta\,(A - c_A)}{4\beta + 6}, \tag{10}$$

with

$$q_I^* = \frac{(1+\beta)\,Q^c - (A-c_A) - (\beta+1)^2\,(c-c_E)}{2\beta+3}, \tag{11}$$

$$q_E^* = \frac{(1+\beta)\,(Q^c + 2\,(A-c_A) + (2+\beta)\,(c-c_E))}{2\beta+3}, \tag{12}$$

and the interior price $P^* = \frac{a+(1+\beta)(C_I+C_E)-\beta(A-c_A)}{2\beta+3}$.

Remark 1 *The polar case $\beta = 0$ represents Cournot competition. For $\beta = 0$, $P = \frac{a+C_I+C_E}{3}, q_I^* = \frac{Q^c-(A-c_A)-(c-c_E)}{3}, q_E^* = \frac{Q^c+2((A-c_A)-(c-c_E))}{3}$. In the symmetric case with marginal cost pricing, $c_A = A, c = c_E$ and, letting $C = C_I = C_E$ denote the common marginal cost of production, we obtain the standard Cournot solution, $q_I^* = q_E^* = \frac{Q^c}{3}, P = \frac{a+C_I+C_E}{3} = C + \frac{a-C}{3}$. As would be expected given symmetric Cournot duopoly in the downstream market, marginal cost pricing in the access market yields an equilibrium outcome where the price is above the socially optimal level and the output correspondingly below the socially optimal level.*

As β increases, downstream competition intensifies and total welfare increases. In the limit, P approaches $\frac{(C_I+C_E)-(A-c_A)}{2}$, which yields $P = C$ in the symmetric case with marginal cost pricing. More generally, we have

Proposition 2 *In an interior solution, for c_A sufficiently close to A, as β increases, the total welfare increases.*

Proof. For c_A close enough to A, both the aggregate market output and the efficient firm's output increases in β. Thus welfare increases. See the appendix for details. ■

4.1 Corner solutions[I think these are worth discussing - JQ)

We now discuss the corner solutions when the difference in marginal costs between firms is so great that one of the firms exits the market. Note that although Armstrong, Doyle, and Vickers (1996) and Armstrong and Vickers (1998) use general cost functions, they do not discuss the possibility of corner solutions. In particular, in both papers, the entrant cannot supply the entire market demand at any reasonable prices. Our cost function is not a special case of Armstrong, Doyle, and Vickers (1996) and Armstrong and Vickers (1998). Some of our results are indeed driven by corner solutions.

For very low and very high c_A, only the low cost firm produces in the market in equilibrium. The critical levels of c_A for the corner solution to eventuate depends on β. For a large β, that is, for nearly competitive pricing, the difference in marginal costs required to have corner solutions in equilibrium is small.

For c_A sufficiently large, $c_A > A + \frac{Q^c+(2+\beta)(c-c_E)}{2}$, the cost disadvantage for the entrant is so large that in equilibrium, only the incumbent produces in the final product market. The equilibrium limit price in this case is $P = c_A + c_E$, which is the marginal cost for the high cost firm. This is the same as the standard asymmetric Bertrand equilibrium.

On the other hand, for c_A sufficiently small, $c_A < A - (1+\beta) Q^c + (1+\beta)^2 (c - c_E)$, the cost advantage for the entrant is large such that in equilibrium $q_E > 0$ and $q_I = 0$. The resulting equilibrium price is $P = A + c + \frac{\beta(c_A - A)}{\beta+1}$. For $c_A = A$, we again have the asymmetric Bertrand equilibrium where the market price is pinned down by the marginal cost of the inefficient firm. For $c_A > A$, the limit price is greater than $A + c$. Since the incumbent is making a positive profit by selling access to the incumbent, it is more profitable to exit the downstream market.

Conversely, when $c_A < A$, the limit price is less than $A + c$. To reduce the losses associated with unprofitable sales of access to the entrant, the incumbent remains active in the final product market even when the price is less than the marginal cost of production. Note that in this case, the incumbent is making a loss in both markets and would prefer to shut down.

5 The Efficient Component Pricing Rule

The ECPR requires that the incumbent is compensated for its opportunity cost of providing access:

$$P - C_I = c_A - A \text{ or } c_A = A + (P - C_I).$$

Taking into consideration the post-entry maket price, in our framework, the ECPR or the modified ECPR gives:

Proposition 3 *For $c > c_E$, the ECPR gives $c_A > A$ for sufficiently small β and $c_A = A$ when β is large. In particular, for the interior solution, the ECPR price is equal to:*

$$c_A^{ECPR} = A + \frac{Q^c - (1+\beta)(c - c_E)}{2}. \tag{13}$$

For $c < c_E$, the ECPR always deters entry.

Proof. See the appendix. ■

The ECPR compensates the incumbent for the opportunity cost of providing access and thus deters inefficient entry. When the entrant is more efficient, and the downstream market is imperfectly competitive, the incumbent's opportunity cost of providing access includes foregone revenues and is greater than A. As β increases, the forgone profit decreases and the ECPR access price decreases. For sufficiently large β, the inefficient incumbent exits the market so that the opportunity cost of providing access is equal to A. The ECPR never prescribes below-cost pricing since the incumbent can choose to exit the final product market.

When the entrant is less efficient, the ECPR always gives a corner solution with $q_E = 0$, $q_I > 0$, and $P = c_A + c_E$. The ECPR does not give us information on how the access price should be set since providing access does not incur any opportunity cost for the incumbent. In this case, any access price that keeps the entrant out of the market is consistent with reasoning behind the ECPR. From the welfare point of view, the regulator chooses the smallest c_A required to deter inefficient entry.

6 Optimal Access Pricing

We assume that the regulator maximizes the unweighted sum of consumer surplus and the profits of the two firms, subject to the incumbent breaking even:

$$\max_{c_A} CS + \pi_I + \pi_E \text{ s.t. } \pi_I \geq 0.$$

The solution of this problem yields the various propositions below covering different cases on the efficiency of the entrant.

Proposition 4 *For* $c_E < c$*,* $c_A^* \leq A$ *and the break even constraint binds. The equality holds when* β *is sufficiently large. For* $c_E = c$*,* $c_A^* < A$*, and* $c_A^* = A$ *only when* $\beta \to \infty$*.*

Proof. For $c_E < c$, the first best price is $P^{FB} = A + c_E$. Achieving such pricing requires $c_A < A$. Thus, for interior solution, the break-even constraint binds. For the corner solution $q_E > 0$ and $q_I = 0$, the break even constraint gives $c_A^* = A$. When $c_E = c$, the corner solution does not eventuate, and $c_A^* = A$ only in the limit when $\beta \to \infty$. See the appendix for the optimal c_A^* levels. ■

When β is small enough, both firms produce in the final goods market. The regulator prices access below cost, and adjusts this access charge to ensure that the incumbent makes enough profit in the downstream market to break even. For sufficiently large β, only the efficient firm remain in the market. Marginal cost pricing is the lowest access charge to satisfy the break even constraint. The optimal access price increases as β increases and eventually reaches A. If the regulator does not face a break-even constraint, the unconstrained optimal access price also increases as β increases and eventually reaches A. As the market gets more competitive, there is less need to use the access charge to promote competition.

From the above proposition, the following observation is immediate.

Corollary 1 *If* $c_E \leq c$*, and* β *is sufficiently large, the optimal access charge is ECPR .*

For sufficiently large β, constrained maximization yields $c_A = A$ and the resulting market price is $P = A + c$ with $c_A = A + (P - A - c)$, which coincides with the ECPR access price. In the limit, the regulator does not have to use access price to promote competition, so that as $\beta \to \infty$, $c_A^* \to A$. This result generalizes the observation that the ECPR is optimal if the market is perfectly competitive in the absence of the break even constraint.

The above propositions show that when the potential entrant is equally or more efficient than the incumbent, the regulator does not have an incentive to set access pricing above cost. However, when the potential entrant is relatively inefficient, setting a low c_A encourages production from the entrant leading to productive inefficiency. With an inefficient entrant, the optimal access price could be above or below cost.

Proposition 5 *If $c_E > c$, the results can be summarized as follows:*

(i) For sufficiently large cost difference or sufficiently large β, c_A^* always deters entry and thus confirms the ECPR price.

(ii) For small β and small cost difference, $c_A^* < A$ and $c_A^* < c_A^{ECPR}$.

(iii) For some intermediate β range, $c_A^* > A$ and $c_A^* < c_A^{ECPR}$ if the cost difference is small, and $c_A^* = c_A^{ECPR} > A$ for large cost difference.

(iv) For sufficiently large β, $c_A^* = c_A^{ECPR} < A$. For $\beta > \frac{Q^c}{c_E - c}$, $c_A^* = c_A^{ECPR} = A - (c_E - c)$.

Proof. See the appendix for the complete characterization of optimal access pricing. ■

If the entrant is inefficient, the regulator faces a trade-off between productive efficiency and allocative efficiency. Whether or not $c_A^* > A$ depends on the magnitudes of β and c_E. The optimal access charge is not monotonic in either β or c_E. Below cost pricing occurs when β is small and when the difference between c_E and c is small. In this case, promoting competition by below cost pricing is more desirable since the market is not competitive. With small cost difference, encouraging production by the inefficient entry is not as costly either. Below cost pricing also occurs when the market is very competitive. With such competitive intensity, the inefficient firm does not produce and the regulator uses below-cost pricing to get the market price close to $A + c$. For sufficiently large β, the characterization of optimal access pricing is the same as in the case examined by Armstrong (2002) with Bertrand competition and an inefficient entrant.

7 Concluding comments

We have shown that when firms have market power in the downstream product market, and the entrant is equally or more efficient, a social-welfare maximising regulator prices access below its marginal cost. The reduced access charge serves as an instrument to promote downstream competition. Given the constraint that the incumbent should at least break even, the optimal access charge is set below cost and the incumbent makes just enough profit in the downstream market to cover its loss in the upstream market. As competition in the downstream market intensifies, the constrained access price approaches the ECPR. In the absence of the break even constraint, the unconstrained optimal access charge converges to the marginal cost.

When the entrant is inefficient, the regulator faces a trade-off between pro-competitive effects and productive efficiency. The optimal access price can be above or below cost, depending on the extent of the difference in the cost efficiency between the incumbent and the entrant and the intensity of downstream competition. The optimal access price only deters inefficient entry when the entrant is very inefficient and when the market is relatively competitive. When the downstream market is not competitive enough, the regulator finds it optimal to accommodate the inefficient entrant by setting the access price below the ECPR.

Our results also imply that, in a dynamic setting, firms considering investing in a bottleneck facility may be deterred from doing so by the prospect of mandated access and access pricing policies that yield prices below the ECPR and are set as a result of static welfare maximisation exercise by the regulator. That is, deregulation of the downstream market then needs to be coupled with other policy instruments to ensure sufficient upstream investment.

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8 Appendix

Proof. (Proposition 2): Partially differentiating Equation 12 gives $\frac{\partial q_E^*}{\partial \beta} \geq 0$ if $c_A \leq A + \frac{Q^c + \left(2\beta^2 + 6\beta + 5\right)(c - c_E)}{2}$. For $c_A \geq A + \frac{Q^c + (2+\beta)(c - c_E)}{2}$, we have corner solution with $q_E = 0$ and $P = c_A + c_E$. Given that $\frac{Q^c + \left(2\beta^2 + 6\beta + 5\right)(c - c_E)}{2} > \frac{Q^c + (2+\beta)(c - c_E)}{2}$ for $c > c_E$, the efficient entrant's output increases as β increases. Similarly, partially differentiating Equation 11 gives $\frac{\partial q_I^*}{\partial \beta} \geq 0$ for $c_A \leq A + \frac{Q^c - 2(\beta+2)(\beta+1)(c - c_E)}{2}$. Given that $\frac{Q^c - 2(\beta+2)(\beta+1)(c - c_E)}{2} > \frac{Q^c + (2+\beta)(c - c_E)}{2}$ for $c < c_E$, the incumbent's output increases as β increases if the incumbent is efficient. For the market aggregate output, $\frac{\partial Q}{\partial \beta} \geq 0$ if $c_A \leq A + \frac{2Q^c + c - c_E}{4}$. This is satisfied for $c_A = A$, and does not hold for large c_A. Given that $\frac{2Q^c + c - c_E}{4} > \frac{Q^c + (2+\beta)(c - c_E)}{2}$ for $c < c_E$, the aggregate output increases when the incumbent is the efficient firm. For $c_E < c$ and the entrant being the efficient firm, $\frac{\partial Q}{\partial \beta} \geq 0$ for c_A close enough to A. Furthermore, for $c_E < c$, we show below that the optimal $c_A^* < A$. With the optimal access pricing, the aggregate market output increases as β increases. ■

Proof. (Proposition 3): In an interior solution, the ECPR is given by

$$c_A = A + \frac{a + (1+\beta)(C_I + C_E) - \beta(A - c_A)}{2\beta + 3} - C_I.$$

Or

$$c_A = A + \frac{Q^c - (1+\beta)(c - c_E)}{2}. \tag{14}$$

For $c > c_E$, we have an interior solution and this access price is relevant if β is sufficiently small, $\beta \leq \frac{Q^c}{(c - c_E)} - 1$. The access price implied by the ECPR is always above A. For sufficiently large β, we have a corner solution with $q_E > 0$ and $q_I = 0$, in which case the ECPR is given by

$$A + c + \frac{\beta\left(c_A - A\right)}{\beta + 1} - A - c = c_A - A,$$

or

$$c_A = A.$$

For $c < c_E$, with $c_A = A + \frac{Q^c - (1+\beta)(c - c_E)}{2}$, we always have corner solution with $q_I > 0$ and $q_E = 0$. The equilibrium price is $P = c_A + c_E$. The minimum c_A required is $c_A = A + \frac{Q^c + (2+\beta)(c - c_E)}{2}$. ■

Proof. (Proposition 4): Let $c_B\left[c_E\right]$ denote the c_A level at the constrained optimum with $\pi_I\left[c_B\right] = 0$.

$$\frac{\partial TS}{\partial c_A} = \left(P^*\left[c_E\right] - (A + c)\right)\frac{\partial Q^*\left[c_E\right]}{\partial c_A} + \left(c - c_E\right)\frac{\partial q_E^*\left[c_E\right]}{\partial c_A}. \tag{15}$$

It is never optimal for the regulator to set $c_A > A + \frac{1}{2}\left(Q^c + \left(c - c_E\right)(2 + \beta)\right)$ and force the equilibrium $q_I > 0$ and $q_E = 0$.

For any $c_A < A - (1+\beta)\left(Q^c - (1+\beta)\left(c - c_E\right)\right)$ with $q_E > 0$ and $q_I = 0$, the c_A required for break–even is at least A. $A < A - (1+\beta)\left(Q^c - (1+\beta)\varepsilon\right)$ if $\beta > \frac{Q^c}{\varepsilon} - 1$. For an interior solution, $\frac{\partial TS}{\partial c_A} = 0$ gives

$$c_A = A - \frac{(\beta+1)(2\beta+5)\left(c - c_E\right) + (2\beta+1)Q^c}{(2\beta+1)^2} < A. \tag{16}$$

Given this c_A, the downstream price is

$$P = A + c - \frac{2\left(c - c_E\right)(1+\beta)}{2\beta + 1} < A + c \tag{17}$$

The break–even constraint is violated. For an interior solution in the final good market, the optimal access charge is the constrained optimum, c_B:

$$\begin{aligned} & c_B\left[c_E\right] \\ = \quad & A + \frac{\left(4\beta^2 + 8\beta + 5\right)Q^c + 4\left(c - c_E\right)(\beta+1)^2}{2\left(4\beta^2 + 8\beta + 5\right)} \\ & - \frac{(2\beta+3)\sqrt{\left(4\beta^2 + 8\beta + 5\right)\left(Q^c\right)^2 + 4\left(c - c_E\right)^2(\beta+1)^3}}{2\left(4\beta^2 + 8\beta + 5\right)} \\ < \quad & A. \end{aligned}$$

■

Proof. (Proposition 5): Let $\varepsilon \equiv c_E - c > 0$. The optimal access pricing rule is summarized in the following table, where $c_{AI} = A + \frac{(\beta+1)(5+2\beta)\varepsilon-(1+2\beta)Q^c}{(2\beta+1)^2}$ and $\widetilde{c_A} = A + \frac{1}{2}\left(Q^c - \varepsilon\left(2+\beta\right)\right)$.

	$\varepsilon \leq \frac{2Q^c}{9}$	$\frac{2Q^c}{9} < \varepsilon < \frac{Q^c}{4}$	$\frac{Q^c}{4} \leq \varepsilon \leq \frac{2Q^c}{7}$	$\varepsilon > \frac{2Q^c}{7}$
$\beta \leq \frac{2Q^c-5\varepsilon-\sqrt{(2Q^c-7\varepsilon)(2Q^c+\varepsilon)}}{4\varepsilon}$	NA, $\beta < 0$		$\widetilde{c_A} > A$	
$\frac{2Q^c-5\varepsilon-\sqrt{(2Q^c-7\varepsilon)(2Q^c+\varepsilon)}}{4\varepsilon} < \beta \leq \frac{2Q^c-7\varepsilon+\sqrt{(2Q^c-\varepsilon)(2Q^c-9\varepsilon)}}{4\varepsilon}$	$\max\{c_{AI}, c_B[c+\varepsilon]\} < A$	$c_{AI} > A$		$\widetilde{c_A} > A$
$\frac{2Q^c-7\varepsilon+\sqrt{(2Q^c-\varepsilon)(2Q^c-9\varepsilon)}}{4\varepsilon} < \beta \leq \frac{2Q^c-5\varepsilon+\sqrt{(2Q^c-7\varepsilon)(2Q^c+\varepsilon)}}{4\varepsilon}$	$c_{AI} > A$			$\widetilde{c_A} > A$
$\frac{2Q^c-5\varepsilon+\sqrt{(2Q^c-7\varepsilon)(2Q^c+\varepsilon)}}{4\varepsilon} < \beta \leq \frac{Q^c-2\varepsilon}{\varepsilon}$	$\widetilde{c_A} > A$			
$\frac{Q^c-2\varepsilon}{\varepsilon} < \beta \leq \frac{Q^c}{\varepsilon}$	$\widetilde{c_A} < A$			
$\beta > \frac{Q^c}{\varepsilon}$	$A - \varepsilon$			

Table 1: Optimal access charge with $c_E = c + \epsilon$

For $c_E = c+\varepsilon$, it is never optimal for the regulator to set a c_A so low that in equilibrium $q_E > 0$ and $q_I = 0$. Denote the critical c_A level above which $q_I > 0$ and $q_E = 0$ by $\widetilde{c_A}$, $\widetilde{c_A} \equiv A + \frac{1}{2}\left(Q^c - \varepsilon\left(2+\beta\right)\right)$. Note that $\widetilde{c_A} \geq A$ for $\beta < \frac{Q^c-2\varepsilon}{\varepsilon}$. The downstream equilibrium is that for $c_A \leq \widetilde{c_A}$, $q_I > 0$ and $q_E > 0$. Otherwise, $q_I > 0$ and $q_E = 0$. For $c_A \leq \widetilde{c_A}$, taking the FOC of Equation 15 gives $c_A = A + \frac{\varepsilon(\beta+1)(5+2\beta)-(1+2\beta)Q^c}{(2\beta+1)^2}$. Let c_{AI} denote this optimal access charge for an interior downstream equilibrium. For $c_A > \widetilde{c_A}$, the FOC gives $c_A^* = A - \varepsilon$. $c_{AI} \geq \widetilde{c_A}$ if $\varepsilon > \frac{2Q^c}{7}$. For ε large enough, the regulator has the incentive to push the solution into the corner solution such that only the efficient incumbent produces. For $\varepsilon \leq \frac{2Q^c}{7}$, $c_{AI} \leq \widetilde{c_A}$ if

$$\frac{2Q^c - 5\varepsilon - \sqrt{\left(2Q^c - 7\varepsilon\right)\left(2Q^c + \varepsilon\right)}}{4\varepsilon} \leq \beta \leq \frac{2Q^c - 5\varepsilon + \sqrt{\left(2Q^c - 7\varepsilon\right)\left(2Q^c + \varepsilon\right)}}{4\varepsilon}. \tag{18}$$

Note that $\frac{2Q^c-5\varepsilon-\sqrt{(2Q^c-7\varepsilon)(2Q^c+\varepsilon)}}{4\varepsilon} < 0$ if $\varepsilon < \frac{Q^c}{4}$.

$c_{AI} \geq A$ if $\varepsilon \geq \frac{2}{9}Q^c$. For $\varepsilon < \frac{2}{9}Q^c$, $c_{AI} > A$ if $\beta > \frac{2Q^c-7\varepsilon+\sqrt{(2Q^c-\varepsilon)(2Q^c-9\varepsilon)}}{4\varepsilon}$.

Finally, $A-\varepsilon > \widetilde{c_A}$ if $\beta > \frac{Q^c}{\varepsilon}$.

For $\varepsilon \leq \frac{2}{9}Q^c$ and $\beta \leq \frac{2Q^c-7\varepsilon+\sqrt{(\varepsilon-2Q^c)(9\varepsilon-2Q^c)}}{4\varepsilon}$, $c_{AI} < A$, $P^*[c_{AI}] > A+c$, and

$$
\begin{aligned}
& c_B[c+\varepsilon] \\
= \quad & A+\frac{\left(4\beta^2+8\beta+5\right)Q^c-4\varepsilon(\beta+1)^2-(2\beta+3)\sqrt{\left(4\beta^2+8\beta+5\right)(Q^c)^2+4\varepsilon^2(\beta+1)^3}}{2\left(4\beta^2+8\beta+5\right)} \\
< \quad & A.
\end{aligned}
$$

For this parameter range, $c_A^* = \max\{c_{AI}, c_B[c+\varepsilon]\} < A$. ■