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ORIGINAL ARTICLE

On the performance of endogenous access pricing

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Abstract Endogenous access pricing (ENAP) is an alternative to the traditional procedure of setting a fixed access price that reflects the regulator's estimate of the supplier's average cost of providing access. Under ENAP, the access price reflects the supplier's actual average cost of providing access, which varies with realized industry output. We show that in addition to eliminating the need to estimate industry output accurately and avoiding a divergence between upstream revenues and costs, ENAP can enhance the incentive of a vertically integrated producer to minimize its upstream operating cost. However, ENAP can sometimes discourage surplus-enhancing investment.

Keywords Endogenous access pricing · Regulation · Vertical integration

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1 Introduction

Vertically integrated regulated enterprises often sell essential inputs to retail rivals. For instance, owners of telecommunications networks commonly sell network access

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to rival suppliers of retail telecommunications services. The price at which a regulated vertically integrated provider (VIP) supplies network access is often set equal to the VIP's expected unit cost of supplying access. This pricing methodology ensures that the VIP's expected revenue from supplying access (both to itself and to retail rivals) is equal to the VIP's expected cost of supplying the access. Furthermore, each supplier's total payment for access is proportional to its consumption of access under such a pricing methodology. As Klumpp and Su (2010, p. 71) observe, such a *revenue neutral* pricing methodology can thereby reasonably be construed as satisfying the common legal mandate that access charges be fair, reasonable, and nondiscriminatory. Because they strive to match the revenues and costs of supplying access, such revenue neutral pricing methodologies also help to ensure that the regulated enterprise has "a reasonable opportunity to recover the economic costs of long-lived, nonsalvageable investments that it [makes] to serve its customers" (Sidak and Spulber 1998, p. 177).[1]

Revenue neutral access pricing policies can be implemented in at least two distinct ways. Under what we call *exogenous access pricing* (EXAP), the regulator sets the access price equal to her *ex ante* estimate of the VIP's average cost of supplying access. This access charge, which is set before retail competition takes place, governs all payments to the VIP by retail rivals. Under *endogenous access pricing* (ENAP), the regulator effectively sets an access charge that reflects the VIP's actual, realized unit cost of supplying access rather than an estimate of this cost (Fjell et al. 2010). The regulator can readily implement such an access charge via a two stage procedure like the following. Initially, the regulator specifies a fixed, unit access price (w_0) that will prevail throughout the coming period (e.g., a year).[2] Retail suppliers must pay this price for each unit of access that they secure during the period. Then, a settling up process is implemented at the end of the period. Under this process, the VIP's actual unit cost of supplying access (w_1) is first established. This cost is the ratio of the VIP's realized total cost of supplying access to the number of units of access that the VIP supplied during the period. A supplier that purchased A_0 units of access during the period is then required to make an additional payment of $[w_1 - w_0]\, A_0$ to the VIP, so that the supplier's total payment over the entire period for A_0 units of access is $w_1 A_0$.[3]

The Australian Competition and Consumer Commission (ACCC) employed a settlement process of this type when setting access charges in the Australian telecommunications industry in 2003. The process adjusted payments for a key network element—unconditioned local loop service (ULLS)—to reflect the realized demand for ULLS

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[1] The efficient component pricing rule for setting access prices (e.g., Baumol et al. 1997) might be viewed as a revenue neutral policy in the sense that it sets the price of access equal to VIP's unit cost of supplying access, including relevant opportunity costs. The total element long run incremental cost (TELRIC) methodology employed to set prices for wholesale services in the U.S. telecommunications industry might be viewed as a variant of a revenue neutral access pricing methodology. Under the TELRIC methodology, the unit price set for a relevant wholesale service can be viewed as an approximation of the estimated minimum feasible average cost of supplying the service. See Tardiff (2002), for example.

[2] w_0 might reflect the regulator's estimate of the VIP's unit cost of supplying access, for instance.

[3] The settlement payment, $[w_1 - w_0]\, A_0$, can be negative, in which case the VIP would compensate the supplier for the "excess" access payments it made during the period in question. If there is a concern that an industry participant might not deliver the monies it owes at the end of a period, the participant can be required to post a financial bond at the start of the period.

(ACCC 2003). See Fjell et al. (2010) for further discussion of this policy and other policies that entail similar *ex post* settling up procedures.

We find that ENAP often provides the VIP with stronger incentives to minimize its upstream production costs than does EXAP. This is the case because the VIP does not anticipate under ENAP the same strategic gain from inflating its fixed cost of production that it perceives under EXAP. To explain this difference most simply, suppose the VIP's only production cost is its upstream fixed cost. Also suppose the only cost a rival incurs is the access charges it pays to the VIP. In this setting, a rival's marginal cost of expanding output under EXAP is $\widehat{w}$, the established access price. The VIP's corresponding perceived marginal cost of increasing its retail output is 0. Consequently, the VIP enjoys a perceived unit retail cost advantage of $\widehat{w}$ under EXAP. This advantage increases as a higher upstream fixed cost of production increases $\widehat{w}$.

The VIP does not perceive the same cost advantage under ENAP. The average cost of supplying access declines as the VIP expands its retail output, and so the equilibrium access price under ENAP declines, *ceteris paribus*. The corresponding decline in the VIP's access revenue causes the VIP to perceive a strictly positive cost of expanding its retail output. In fact, as we demonstrate below, a VIP perceives itself to have the same unit cost of expanding retail output that its rivals perceive under ENAP. Therefore, the VIP does not increase its effective cost advantage over its rivals by increasing its upstream fixed cost of production under ENAP. Consequently, ENAP typically provides stronger incentives than does EXAP for the VIP to avoid inefficient increases in upstream fixed costs of production.[4]

Although ENAP can provide stronger incentives than EXAP to minimize upstream production costs, ENAP may induce a VIP to undertake inefficiently low levels of surplus-enhancing infrastructure investment, including investment that reduces the VIP's unit variable cost of supplying access. This is the case because investment (and the associated increase in fixed production costs) does not deliver the same strategic advantage under ENAP that it delivers under EXAP. The reduced productive investment that can arise under ENAP can lead to a lower level of welfare than arises under EXAP.[5]

We develop and present these conclusions as follows. Section 2 describes the primary model that we analyze. Section 3 demonstrates that the VIP typically will avoid inefficient inflation of its cost of supplying access under ENAP. Section 4 identifies conditions under which the VIP will allow such inefficient cost inflation to arise under EXAP. Section 5 identifies conditions under which the smaller amount of productive investment that arises under ENAP can reduce welfare. Section 6 provides concluding observations and discusses extensions of our model. The "Appendix" outlines the proofs of all formal conclusions. Fjell et al. (2013) provide additional proof details.

Before proceeding, we explain how our analysis contributes to the literature. To our knowledge, Fjell et al. (2010) is the only systematic study of ENAP to date. The

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[4] As Valletti and Estache (1999, p. 19) observe, if a regulator has limited knowledge of the minimum possible cost of supplying access, the regulated supplier of access may find it profitable to exaggerate these costs or "engage in wasteful practices" that allow these costs to rise above the minimum feasible level.

[5] This conclusion holds for both demand-enhancing investment (e.g., Klumpp and Su 2010; Vareda 2010, 2011 and cost-reducing investment (e.g., Vareda 2010).

authors demonstrate how ENAP can limit the strategic advantage that a VIP enjoys over its rivals under EXAP in a setting where the VIP's cost structure is exogenous and immutable. We extend this work in part by demonstrating how ENAP can limit the incentives that can arise under EXAP to allow (endogenous) fixed production costs to rise above their minimum feasible level.

Although they do not analyze ENAP explicitly, Boffa and Panzar (2012) demonstrate the merits of an institutional arrangement that delivers incentives similar to those that arise under ENAP. The authors consider a setting in which retail suppliers jointly own an upstream asset (e.g., a telecommunications network). The fraction of the asset that each retail supplier owns is equal to the supplier's (endogenous) share of equilibrium retail output. This ownership structure provides strong incentives for all suppliers to expand their retail output, in part to reduce the upstream unit cost of production (in light of the prevailing scale economies) and thereby increase upstream profit. Like Fjell et al. (2010), Boffa and Panzar (2012) consider exogenous production technologies and assume that the upstream supplier operates at minimum cost. In contrast, we analyze the technology choices that ENAP induces.

Klumpp and Su (2010) examine the level of demand-enhancing investment that EXAP induces.[6] The authors identify conditions under which EXAP induces a VIP to undertake more than the surplus-maximizing level of demand-increasing investment. This over-investment arises because of the strategic advantage that increased investment costs can confer upon the VIP under EXAP. We demonstrate that because the same strategic advantage does not arise under ENAP, a VIP that operates under ENAP may undertake less than the surplus-maximizing level of investment.

2 The model

We consider a setting in which a vertically integrated provider (VIP) competes with N retail rivals to sell a homogenous product to consumers. The VIP is also the sole supplier of an essential input (e.g., access to the VIP's network). Exactly one unit of the input is required to produce each unit of the retail product. For simplicity, we abstract from retail production costs other than the cost of acquiring the essential input from the VIP.[7] The unit cost of acquiring the input is simply the regulated access price, w, that is charged for the input.

The VIP incurs a fixed cost, F, to produce the input. This fixed cost might be viewed as the cost the VIP incurs to build and maintain its network. The minimum fixed cost required for operation is $\underline{F}$. If the VIP finds it profitable to do so, it can increase F above $\underline{F}$, to a maximum of $\overline{F}$. Such cost inflation serves only to increase the VIP's upstream operating cost—it does not reduce the VIP's downstream cost or improve network performance.[8] Therefore, cost inflation provides no direct value to

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[6] See Vareda (2010, 2011) for useful related investigations of incentives for quality-enhancing network investment.

[7] The concluding discussion considers positive and asymmetric retail production costs.

[8] Section 5 extends the analysis to consider settings in which increases in F reduce the VIP's unit variable cost of supplying access.

the VIP. However, as demonstrated below, such cost inflation may benefit the VIP by increasing the access price that is charged to retail rivals.[9]

$\overline{F} - \underline{F}$ can be viewed as the maximum amount of cost inflation the VIP can undertake without detection, and thus without penalty. For analytic simplicity, we assume that additional cost inflation would be detected with sufficiently high probability and penalized sufficiently severely that the VIP never increases F above $\overline{F}$.[10] To ensure that industry operation is potentially profitable, $\underline{F}$ is assumed to be less than the maximum variable profit that can be secured in the industry.[11]

The access price that is charged for the essential input varies with the prevailing access pricing regime. Under exogenous access pricing (EXAP), the access price is $w = \frac{F}{Q^e}$, where Q^e denotes the level of total industry output that the regulator expects to be produced. The regulator announces Q^e and F is observed before the industry producers choose their outputs under EXAP. Consequently, the producers consider the identified access price to be fixed and exogenous when they choose their retail outputs.

Under endogenous access pricing (ENAP), the regulator announces that the access price will be $w(Q) = \frac{F}{Q}$, where Q is the level of industry output that ultimately arises. Therefore, under ENAP, each producer realizes that an increase in its retail output will cause the access price that ultimately prevails to decline, *ceteris paribus*.

We will let q_0 denote the VIP's retail output and q_i denote the output of retail rival $i \in \{1, \ldots, N\}$. The VIP's profit (π_0) is the sum of the revenue it secures from providing access to its retail rivals ($w \sum_{i=1}^{N} q_i$) and its retail profit, less its fixed cost of production (F). The VIP's retail profit is the product of its output (q_0) and the prevailing market-clearing retail price, $P(Q)$, where $Q = \sum_{j=0}^{N} q_j$.[12] Formally, the VIP's profit is:

$$\pi_0(q_0, q_1, \ldots, q_N, w, F) = P(Q)q_0 + w \sum_{i=1}^{N} q_i - F. \tag{1}$$

The corresponding profit (π_i) of retail rival $i \in \{1, \ldots, N\}$ is the product of the rival's retail output (q_i) and its profit margin ($P(Q) - w$). Formally:

$$\pi_i(q_0, q_1, \ldots, q_N, w) = [P(Q) - w]\, q_i \quad \text{for} \quad i \in \{1, \ldots, N\}. \tag{2}$$

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[9] Klumpp and Su (2010) analyze a setting in which the VIP can increase the quality of the input it supplies by incurring a higher fixed cost of production. The increased quality enhances the demand for the homogeneous product sold by the retail suppliers. The authors show that the VIP may provide excessive quality under EXAP in part because retail rivals pay a large share of the costs of enhanced quality.

[10] Alternatively, the VIP might face expected penalty $\Phi(F - \underline{F})$ when it chooses $F \geq \underline{F}$, where $\Phi(\cdot)$ is an increasing, convex function of F. This formulation would provide similar qualitative conclusions, but with additional computational complexity.

[11] To illustrate, when industry demand is linear so that the market-clearing price for industry output Q is $P(Q) = a - bQ$ (where $a > 0$ and $b > 0$ are constants), the profit-maximizing retail output for a monopolist is $\frac{a}{2b}$, and the corresponding price is $\frac{a}{2}$. Therefore, the maximum variable profit of the monopolist in this setting is $\frac{a^2}{4b}$.

[12] Thus, $P(Q)$ represents the inverse demand curve for the retail product.

The timing in the model is as follows. First, the regulator announces the access pricing regime that will be implemented. Second, the VIP chooses $F \in \left[\underline{F}, \overline{F}\right]$. Third, the regulator observes F and reports her observation (truthfully). This report determines the prevailing access pricing rule ($w(Q) = \frac{F}{Q}$) if the regulator has implemented ENAP. If she has implemented EXAP, the regulator also announces the industry output she expects to be produced (Q^e), which determines the access price that will prevail ($w = \frac{F}{Q^e}$). Fourth, the VIP and its N retail rivals choose their outputs simultaneously and independently. Finally, the market clearing price is determined, the firms sell their outputs at this price, and the N retail rivals deliver the required access payments to the VIP.

3 Endogenous access pricing

We begin our assessment of the relative impacts of ENAP and EXAP on the incentives for upstream cost minimization by examining the outcomes that arise under ENAP. Equation (1) implies that since $\sum_{i=1}^{N} q_i = Q - q_0$ and $w = \frac{F}{Q}$, the VIP's profit-maximizing output under ENAP is determined by:

$$\frac{\partial \pi_0}{\partial q_0} = 0 \quad \Leftrightarrow \quad P\left(Q\right) + q_0 P'\left(Q\right) - \frac{F}{Q} + \frac{q_0 F}{Q^2} = 0. \tag{3}$$

Similarly, from Eq. (2), entrant i's profit-maximizing output under ENAP is determined by:

$$\frac{\partial \pi_i}{\partial q_i} = P\left(Q\right) + q_i P'\left(Q\right) - \frac{F}{Q} + \frac{q_i F}{Q^2} = 0 \quad \text{for} \quad i = 1, \ldots, N. \tag{4}$$

It is apparent from Eqs. (3) and (4) that the VIP and each retail rival will produce the same level of output in equilibrium under ENAP. Formally, employing a "$\sim$" above a variable to denote an outcome under ENAP and using a "*" to denote an equilibrium outcome, Eqs. (3) and (4) imply:

$$\widetilde{q}_0^* = \widetilde{q}_i^* = \frac{\widetilde{Q}^*}{N+1} \quad \text{for} \quad i = 1, \ldots, N. \tag{5}$$

Each retail supplier produces the same equilibrium output under ENAP because the VIP and each retail rival effectively face marginal cost $\widetilde{w} = \frac{F}{\widetilde{Q}}$ under ENAP. The VIP faces this marginal cost because its wholesale profit under ENAP is:

$$\widetilde{w} \sum_{i=1}^{N} \widetilde{q}_i - F = \frac{F}{\widetilde{Q}} \left[\widetilde{Q} - \widetilde{q}_0\right] - F = -\left[\frac{F}{\widetilde{Q}}\right] \widetilde{q}_0 = -\widetilde{w}\widetilde{q}_0. \tag{6}$$

Therefore, should the VIP attempt to raise its rivals' unit cost of retail production by artificially inflating its fixed cost of production, the VIP effectively raises its own operating cost symmetrically. Consequently, such cost inflation increases the VIP's cost without providing any strategic advantage. As a result, the VIP generally will refrain from such cost inflation under ENAP, as Proposition 1 reports.

Proposition 1 *Suppose that for all* $Q \geq 0$*: (i)* $P''(Q) \leq 0$*; and (ii)* $P'''(Q)$ *is either negative, or positive and sufficiently close to zero. Then the VIP always operates with the cost-minimizing technology under ENAP, i.e.,* $\widetilde{F}^{*} = \underline{F}$*.*

The structure imposed on the market demand curve in Proposition 1 is sufficient, but not necessary, to ensure that the VIP does not inflate its upstream operating cost (F) under ENAP. The structure promotes diminishing increases in the VIP's profit as F increases. An increase in F increases the rivals' marginal cost of production and thereby induces them to reduce their output. The output reduction raises the market-clearing retail price, which enhances the VIP's profit, *ceteris paribus*. When the inverse demand curve is concave, successive reductions in rival output produce successively smaller increases in the market price, generating diminishing increases in the VIP's profit. Consequently, as long as the VIP finds it unprofitable to increase F marginally above $\underline{F}$ under ENAP (as will be the case under the identified conditions), the VIP will find it unprofitable to increase F substantially above $\underline{F}$.

4 Exogenous access pricing

Although upstream cost inflation typically is not profitable for the VIP under ENAP, such inflation can provide strategic benefits to the VIP that outweigh the corresponding costs under EXAP. To facilitate the identification of conditions under which the VIP will find it profitable to intentionally inflate its costs under EXAP, it is convenient to consider the setting in which the industry demand curve is linear.[13]

Assumption 1 $P(Q) = a - bQ$, where $a > 0$ and $b > 0$ are parameters.

Recall that the access price is $\widehat{w} = \frac{F}{Q^e}$ under EXAP.[14] Therefore, to characterize $\widehat{w}$, it is necessary to specify the total output the regulator expects to arise in equilibrium (Q^e). To abstract from forecasts of industry activity that are (intentionally or unintentionally) biased, we assume the regulator estimates the equilibrium output correctly, so $Q^e = \widehat{Q}^{*}$.[15]

Proposition 2 identifies the equilibrium outcomes under EXAP in this setting. The proof of the proposition employs backward induction. First, the output that each industry supplier will produce under EXAP, given an established access price, is identified. Then the access price that will prevail under EXAP when the VIP's fixed cost is F is characterized. Finally, the VIP's profit under EXAP as a function of F is determined, which permits identification of the VIP's profit-maximizing fixed cost under EXAP.

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[13] Klumpp and Su (2010) also analyze a setting in which the demand for the retail product is linear and access costs are the only costs of retail production.

[14] Here and throughout the ensuing analysis, we will employ a "^" above a variable to denote an outcome under EXAP.

[15] The concluding discussion considers alternative possibilities.

Proposition 2 *Suppose Assumption 1 holds. Then the VIP operates with the cost-minimizing technology under EXAP if it faces fewer than three retail rivals (i.e.,* $\widehat{F}^* = \underline{F}$ *if* $N < 3$*). In contrast, if the VIP faces three or more rivals and* $\underline{F}$ *is sufficiently small (e.g.,* $\underline{F} < \frac{a^2}{16b}$*), then the VIP will set* $\widehat{F}^* = \min\left\{\frac{3a^2[N-2]}{16bN}, \overline{F}\right\} > \underline{F}$ *under EXAP.*

The conclusions in Proposition 2 reflect the following considerations. The VIP experiences a gain and a loss when it increases its fixed cost of production above $\underline{F}$. The gain stems from the more pronounced strategic advantage the VIP enjoys in its interaction with retail competitors. The enhanced strategic advantage arises because the access price under EXAP ($\widehat{w} = \frac{F}{Q^e}$) increases as F increases, *ceteris paribus*. Under EXAP, the VIP's rivals incur marginal cost $\widehat{w} > 0$, whereas the VIP's marginal cost of retail output is 0. Therefore, the VIP's marginal cost advantage increases as F, and thus $\widehat{w}$, increases. This increased cost advantage increases the VIP's share of retail output and thus the VIP's profit, *ceteris paribus*.[16]

The loss the VIP incurs when it increases F above $\underline{F}$ is the fraction of the increase in F the VIP is required to bear. Under EXAP, the VIP's expected wholesale profit (i.e., the difference between its revenue from supplying access and the corresponding cost) is:

$$\widehat{w}\sum_{i=1}^{N}\widehat{q}_i^* - F = \frac{F}{Q^e}\left[Q^e - \widehat{q}_0^*\right] - F = -\left[\frac{\widehat{q}_0^*}{Q^e}\right]F. \tag{7}$$

Equation (7) implies that the VIP bears the fraction $\frac{\widehat{q}_0^*}{Q^e}$ of the fixed cost it implements.

These observations imply that when the VIP faces few retail rivals, it bears a relatively large share of the cost of increasing F while securing an increased retail cost advantage that is of relatively limited value because the VIP faces few rivals. Consequently, as Proposition 2 reports, the VIP refrains from artificial inflation of its fixed cost of production when it faces few (i.e., less than three) retail rivals. In contrast, when the VIP faces many retail rivals, the cost advantage it secures from increasing F is relatively valuable and the fraction of the increase in F it bears is relatively small. Consequently, the VIP may find it profitable to increase F above its minimum feasible level, $\underline{F}$. Indeed, the VIP will undertake such cost inflation unless $\underline{F}$ is so large (e.g., $\underline{F} > \frac{a^2}{16b}$) that even when $F = \underline{F}$, the prevailing access price is sufficiently high that the VIP produces a large share of equilibrium retail output. In this case, an increase in F above $\underline{F}$ obligates the VIP to bear a large fraction of the increase in F while enhancing a strategic cost advantage that is of limited value because rivals are producing relatively little output.

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[16] As Lemma 1 in the "Appendix" reports, the VIP's retail output increases whereas the output of each retail rival declines as $\widehat{w}$ increases under EXAP.

5 A setting with productive fixed investment

Although ENAP can increase welfare by limiting unproductive investment in fixed operating costs, it can also reduce welfare in some settings by limiting productive fixed investments. To illustrate this conclusion, consider the *setting with variable access costs*. This setting, which parallels the setting in Vareda (2010), is the same setting analyzed above with the exception that the VIP incurs a strictly positive unit variable cost of supplying access, $c(\cdot)$. This unit cost declines at a decreasing rate as the VIP's fixed cost (F) increases. Formally, $c(F) = c_0 - r(F)$, where $c_0 > 0$ and $r(F) \in [0, c_0)$, with $r(0) = 0, r'(F) > 0$, and $r''(F) < 0$.[17] The cost-minimizing level of F is assumed to be strictly positive and finite for all finite levels of industry output.

Proposition 3 reports that ENAP continues to induce relatively little fixed investment in this new setting under the conditions where it does the same in the setting of Proposition 2.

Proposition 3 *Suppose Assumption 1 holds and the VIP faces three or more rivals. Then the VIP will implement a smaller level of F under ENAP than under EXAP in the setting with variable access costs.*

Although the VIP's investment in F under EXAP and ENAP can be ranked systematically in the setting of Proposition 3, welfare (the sum of consumer surplus and industry profit) cannot be similarly ranked. When increased investment in F has a relatively limited impact on the VIP's unit variable cost of supplying access ($c(\cdot)$), the higher F that EXAP induces can lead to a relatively high access charge and a relatively low level of welfare. In contrast, when $c(\cdot)$ declines relatively rapidly with F, the higher F that arises under EXAP can generate a lower access charge and higher level of welfare than arise under ENAP.

This observation is illustrated in Table 1, which records equilibrium fixed investments, access prices, and welfare under EXAP ($\widehat{F}^*$, $\widehat{w}^*$, and $\widehat{W}^*$) and under ENAP ($\widetilde{F}^*$, $\widetilde{w}^*$, and $\widetilde{W}^*$) in the setting of Example 1. In this example, the VIP faces four rivals (so $N = 4$), industry demand is linear ($P(Q) = 10 - Q$), and the VIP's unit variable cost of supplying access given fixed investment F is $c(F) = 7 - \beta\sqrt{F}$. In this formulation, β is a parameter that influences the rate at which the firm's marginal cost of production declines as its fixed cost of production increases. The higher is β, the more rapidly the VIP's variable unit cost declines as F increases. Table 1 also reports the welfare-maximizing fixed investment (F_m) and the maximum feasible level of welfare ($W_{\max}$) in this setting.

Table 1 reports that in the setting of Example 1, welfare is higher under ENAP than under EXAP when $\beta \le 0.80$, so higher fixed investment reduces $c(\cdot)$ relatively slowly. In contrast, when $\beta \ge 0.90$, the increased fixed investment that arises under EXAP leads to a lower equilibrium average cost of supplying access, and thus a lower access price and a higher equilibrium level of welfare.

Corresponding conclusions arise in other settings where the VIP's fixed investment has social value. For example, increased network investment might increase the quality

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[17] $\underline{F} = 0$ in this setting because higher values of F always reduce the VIP's unit variable cost of production.

Table 1 Fixed costs (F), access prices (w), and welfare (W) in Example 1

β	$\widehat{F}^*$	$\widetilde{F}^*$	F_m	$\widehat{w}^*$	$\widetilde{w}^*$	$\widehat{W}^*$	$\widetilde{W}^*$	$W_{\max}$
0	0.844	0.0	0.0	7.375	7.0	3.375	4.375	4.5
0.10	0.993	0.008	0.023	7.333	6.994	3.487	4.392	4.523
0.20	1.158	0.033	0.094	7.277	6.977	3.638	4.444	4.592
0.30	1.345	0.075	0.222	7.208	6.947	3.828	4.533	4.712
0.40	1.563	0.138	0.425	7.125	6.905	4.063	4.662	4.891
0.50	1.819	0.227	0.735	7.027	6.848	4.348	4.838	5.143
0.60	2.127	0.346	1.205	6.911	6.775	4.696	5.068	5.488
0.70	2.504	0.507	1.934	6.776	6.683	5.121	5.364	5.960
0.80	2.973	0.722	3.114	6.616	6.569	5.645	5.745	6.618
0.90	3.568	1.013	5.148	6.427	6.428	6.299	6.233	7.563
1.00	4.341	1.412	9.0	6.201	6.254	7.129	6.866	9.0

of the product that the VIP and its rivals supply, thereby increasing industry demand for the retail product (as in Vareda 2011). In such settings, the increased fixed investment that typically arises under EXAP can generate a higher level of welfare than arises under ENAP, particularly when the impact of F on industry demand is pronounced.

6 Conclusions

We have shown how endogenous access pricing (ENAP) can create stronger incentives than exogenous access pricing (EXAP) for a VIP to minimize upstream production costs. The stronger incentives arise because ENAP effectively induces the VIP to perceive the same marginal cost of production that its retail rivals face. Consequently, increases in upstream fixed costs of production (F) do not increase the VIP's competitive advantage over its retail rivals as such cost increases do under EXAP.

When increases in F enhance industry surplus, the reduced strategic benefit the VIP derives from these increases under ENAP can cause the VIP to deliver substantially less than the surplus-maximizing level of F. Therefore, although ENAP can enhance welfare by encouraging upstream cost minimization, it can sometimes induce inefficiently small levels of surplus-enhancing investment, and thereby reduce welfare below the level that arises under EXAP.[18]

ENAP offers one additional advantage relative to EXAP that merits brief mention. The access price that is established under EXAP varies with the level of industry output the regulator expects to arise in equilibrium. If the regulator over-estimates (under-estimates) actual industry output, the access price established under EXAP will generate access revenue below (in excess of) the VIP's fixed cost of production (i.e., $\left[\frac{F}{Q^e}\right]\widehat{Q}^* \lesseqgtr F$ as $Q^e \gtreqless \widehat{Q}^*$). This fact has two primary implications. First,

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[18] As Klumpp and Su (2010) demonstrate, EXAP can sometimes induce a VIP to undertake more than the efficient level of quality-enhancing investment. In such cases, ENAP can sometimes limit such over-investment because it provides weaker incentives than EXAP for the VIP to increase F.

the VIP may not secure the intended level of wholesale profit under EXAP, whereas ENAP ensures that wholesale revenue matches wholesale cost. Second, EXAP can invite strategic lobbying to influence the regulator's estimate of equilibrium industry output. Such lobbying serves no purpose under ENAP because the access price that is ultimately established varies only with the realized level of industry output, not with the regulator's estimate of this output.

We have analyzed simple settings for expositional and analytic convenience. More general results can be derived. For instance, Proposition 1 (which states that the VIP will not intentionally inflate its production costs under ENAP) continues to hold in many settings where the VIP and its rivals operate with positive marginal production costs.[19] Furthermore, although the exact conditions under which the VIP will inflate its fixed cost of production under EXAP are more complex when industry suppliers incur positive marginal production costs, these conditions reflect the basic message of Proposition 2. In particular, the VIP often will set F above $\underline{F}$ when it faces many retail rivals, but will tend to set $F = \underline{F}$ when it faces few rivals.[20,21]

Future research should account explicitly for the difficulties that regulators encounter in estimating a VIP's average cost of supplying access. Future research should also examine the performance of ENAP and EXAP under different forms of retail competition. For instance, retail suppliers might market differentiated products and engage in price competition. In such settings, the VIP can incur an opportunity cost of expanding its retail output. Consequently, ENAP and EXAP may have different effects on the VIP's investment incentives and on the incentives of retail rivals to make or buy essential inputs (e.g., Sappington 2005; Gale and Weisman 2007; Mandy 2009).

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Appendix

Proof of Proposition 1 From (1) and (5), the VIP's equilibrium profit under ENAP is:

$$\pi_0^* = \left[\frac{Q^*}{N+1}\right] P\left(Q^*\right) + \frac{F}{Q^*}\left[\frac{NQ^*}{N+1}\right] - F = \frac{1}{N+1}\left[Q^* P\left(Q^*\right) - F\right]. \quad (8)$$

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[19] This is the case, for example, if market demand is linear and the VIP's marginal cost of retail production (c_0) is no less than the marginal cost of the retail rivals (c). If $c_0 < c$, the possibility arises that an increase in the equilibrium access charge caused by an increase in F under ENAP might benefit the VIP by particularly disadvantaging its less efficient retail rivals. Of course, the relatively strong incentive for upstream cost inflation persists under EXAP even when $c_0 < c$.

[20] For simplicity, we have abstracted from financial penalties that the regulator might impose on the VIP if she determines that F exceeds $\underline{F}$. In many settings, the VIP will continue to raise F above $\underline{F}$ under EXAP as long as such penalties are not too pronounced.

[21] Of course, even when increases in F do not enhance industry surplus, a VIP may increase F above $\underline{F}$ under ENAP if doing so provides direct benefits to the VIP (e.g., perquisites for company officials). The incentives for cost inflation remain more pronounced under EXAP than under ENAP in this case, though, for the reasons identified above.

From (3) and (5), equilibrium industry output under ENAP is given by:

$$Q^* [N+1] P(Q^*) + (Q^*)^2 P'(Q^*) - NF = 0 \tag{9}$$

$$\Leftrightarrow Q^* P(Q^*) = \frac{NF - (Q^*)^2 P'(Q^*)}{N+1}. \tag{10}$$

From (8) and (10):

$$\frac{d\pi_0^*}{dF} = -\frac{1}{[N+1]^2} \left\{ \left[(Q^*)^2 P''(Q^*) + 2Q^* P'(Q^*) \right] \frac{\partial Q^*}{\partial F} + 1 \right\}. \tag{11}$$

(11) implies that if $P''(Q^*) \leq 0$ and $\frac{\partial Q^*}{\partial F} \leq 0$, then $\frac{d\pi_0^*}{dF} < 0$, and so the VIP will set $F = \underline{F}$ under ENAP. To determine when $\frac{\partial Q^*}{\partial F} \leq 0$, let $h(Q^*) \equiv Q^* [N+1] P(Q^*) + (Q^*)^2 P'(Q^*)$. It is readily verified that $h''(\cdot) < 0$, and so $h(\cdot)$ is a concave function of Q^*, under the maintained conditions. From (9), Q^* is determined by $h(Q^*) = NF$, and so (9) will have at least one real root when F is sufficiently small. Furthermore, when (9) has two real roots, the larger root of (9) decreases as F increases, and so $\frac{\partial Q^*}{\partial F} < 0$, when $h(\cdot)$ is a concave function of Q^*. Fjell et al. (2013) prove that the larger root of (9) is the relevant root in cases where (9) has two roots. □

The following Lemmas are instrumental in the proof of Proposition 2.

Lemma 1 *Suppose Assumption 1 holds. Then given access price* $\widehat{w}$, *the equilibrium output of the VIP under EXAP is* $\widehat{q}_0^* = \frac{a+\widehat{w}N}{b[N+2]}$. *The equilibrium output of each of the* N *rivals under EXAP is* $\widehat{q}_i^* = \frac{a-2\widehat{w}}{b[N+2]}$ *for* $i = 1, \ldots, N$.

Proof Differentiating (1) and (2) provides:

$$\frac{\partial \pi_0}{\partial q_0} = a - 2bq_0 - b\sum_{j=1}^{N} q_j \quad \text{and} \quad \frac{\partial \pi_i}{\partial q_i} = a - bq_i - bq_0 - b\sum_{j=1}^{N} q_j - w. \tag{12}$$

In equilibrium, $\frac{\partial \pi_0}{\partial q_0} = \frac{\partial \pi_i}{\partial q_i} = 0$. Therefore, from (12):

$$b\sum_{i=1}^{N} q_i = Nbq_0 - wN. \tag{13}$$

Since $\frac{\partial \pi_0}{\partial q_0} = 0$ in equilibrium, (12) and (13) provide the identified expressions for $\widehat{q}_0^*$ and $\widehat{q}_i^*$. □

Lemma 2 *Suppose Assumption 1 holds. Then when the VIP's fixed cost is* F, *the access price that will be set under EXAP is* $\widehat{w}(F) = \frac{1}{2N}\left[a(N+1) - \sqrt{\widehat{G}(F)}\right]$ *where* $\widehat{G}(F) \equiv a^2 [N+1]^2 - 4bFN[N+2]$.

Proof From Lemma 1, $\widehat{Q}^* = q_0^* + \sum_{i=1}^{N} \widehat{q}_i^* = \frac{a[N+1]-wN}{b[N+2]}$.Therefore, when $Q^e = \widehat{Q}^*$, $w = \frac{F}{\widehat{Q}^*} = \frac{bF[N+2]}{a[N+1]-wN}$, which ensures that $\widehat{w}(F)$ is as specified in the lemma. □

Lemma 3 *Suppose Assumption 1 holds. Then for a given fixed cost, F, the VIP's equilibrium profit under EXAP is*:

$$\begin{aligned}\widehat{\pi}_0^*(F) = \frac{1}{4bN^2\left[N+2\right]^2}&\left\{2aN\left[N+4\right]\sqrt{\widehat{G}(F)} + 4bFN^2\left[N+4\right]\left[N+2\right]\right.\\ &\left.-2a^2N\left[N^2+3N+4\right]\right\} - F.\end{aligned}$$

Proof From Lemmas 1 and 2:

$$\widehat{\pi}_0^* = \widehat{q}_0^*\left[a - b\widehat{Q}^*\right] + \widehat{w}\sum_{i=1}^{N}\widehat{q}_i^* - F = \frac{H}{b\left[N+2\right]^2} - F,$$

where $H \equiv [a + \widehat{w}N]^2 + [N+2]\,\widehat{w}N\,[a - 2\widehat{w}]$. Substituting for $\widehat{w}(F)$ from Lemma 2 provides the identified expression for $\widehat{\pi}_0^*(F)$. □

Proof of Proposition 2 Differentiating $\widehat{\pi}_0^*(F)$ provides $\widehat{\pi}_0^{*\prime}(F) = \frac{N+4}{N+2}\left[-\frac{a}{\sqrt{\widehat{G}}} + 1\right] - 1$, which implies $\widehat{\pi}_0^{*\prime}(F) \gtreqless 0 \Leftrightarrow F \lesseqgtr \frac{3a^2[N-2]}{16bN}$. Therefore, $\frac{\partial \pi_0^*}{\partial F} < 0$ (and so $\widehat{F}^* = \underline{F}$) if $N \leq 2$. In contrast, if $N \geq 3$, then $\widehat{F}^* = \min\left\{\max\left(\underline{F}, \frac{3a^2[N-2]}{16bN}\right), \overline{F}\right\}$. Consequently, $\widehat{F}^* > \underline{F}$ if $\underline{F} < \frac{3a^2[N-2]}{16bN}$. This will be the case if $\underline{F} < \frac{a^2}{16b}$, since $z(N) \equiv \frac{N-2}{N}$ is an increasing function of N with $z(3) = \frac{1}{3}$. □

Proof of Proposition 3 The incumbent's profit in the setting with variable access costs is:

$$\pi_0 = q_0 P(Q) + w\sum_{i=1}^{n} q_i - F - c(F)Q. \tag{14}$$

Differentiating (14) provides:

$$\frac{\partial \pi_0}{\partial F} = \frac{\partial}{\partial F}\left\{q_0 P(Q) + w\sum_{i=1}^{n} q_i - F\right\} - \frac{\partial}{\partial F}\left\{c(F)Q\right\} \tag{15}$$

where:

$$\frac{\partial}{\partial F}\left\{c(F)Q\right\} = Q\left[\frac{\partial c(\cdot)}{\partial F}\right] + c(F)\left[\frac{\partial Q}{\partial F}\right] = -Qr'(F) + c(F)\left[\frac{\partial Q}{\partial F}\right]. \tag{16}$$

From Proposition 3 in Fjell et al. (2010), the equilibrium value of Q is the same under EXAP and ENAP for a given F. Therefore, it must be the case that both Q

and the rate at which Q varies with F are the same at each F under EXAP and ENAP. Consequently, (16) implies that for any given F, $\frac{\partial}{\partial F}\{c(F)Q\}$ is the same under exogenous access pricing and endogenous access pricing.

Under the conditions specified in Proposition 2, $\frac{\partial}{\partial F}\left\{q_0 P(Q) + w\sum_{i=1}^{n} q_i - F\right\}$ is strictly positive under EXAP for $F \in [0, \widehat{F}^*)$ (where $\widehat{F}^* > 0$) and strictly negative under ENAP for all $F \geq 0$. Therefore, (15) implies that for each F, $\frac{\partial \pi_0}{\partial F}$ is larger under EXAP than under ENAP, and so the VIP will implement a larger level of F under EXAP than under ENAP in the setting with variable access costs. □

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