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ORIGINAL ARTICLE

Are input prices irrelevant for make-or-buy decisions?

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Abstract The 1996 Telecommunications Act requires incumbent providers to lease network inputs to rivals at cost-based prices in order to jump-start competition. Sappington (Sappington, D. (2005). *American Economic Review, 95*(5), 1631–1638) uses the Hotelling model to show that input prices are irrelevant for an entrant's decision to make or buy an input required for downstream production. We show that this result depends upon the particular model of competition employed. Specifically, input prices are not necessarily irrelevant in the Bertrand vertical differentiation model and are not irrelevant in the Cournot model. It follows that departures from cost-based input prices may distort entrants' make-or-buy decisions in settings of practical interest.

Keywords Access charges · Build-or-buy decisions

JEL Classifications L43 · L51 · L22

1 Introduction

The 1996 Telecommunications Act requires incumbent providers to unbundle their networks and lease the individual network elements to rivals at cost-based prices.[1] The purpose of this unbundling policy is to jump-start competition in markets that

[1] See Hausman and Sidak (1999) for a comprehensive analysis of unbundling policies and their consumer welfare effects. See Borreau and Pinar (2006) for a strategic analysis of unbundling in which the incentives of the incumbent provider to unbundle vary over time as the threat of facilities-based entry becomes more credible.

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have traditionally been characterized as natural monopolies.[2] In addition, the precise meaning of the term "cost-based" prices has been the subject of protracted debate in the economics literature as well as in legal and regulatory proceedings.[3]

Following the passage of the 1996 Act, the Federal Communications Commission (FCC), in concert with the individual state public service commissions, engaged in a massive, multi-year effort to put in place a costing methodology designed to give entrants the right price signals with respect to the decision to make or buy the input required for downstream production.[4] The FCC recently revisited this costing issue out of concern that its TELRIC (total element long-run incremental cost) methodology may serve to distort the entrants' make-or-buy decisions.[5] The following passages underscore the nature of the FCC's concerns.

> Our concerns in evaluating the TELRIC pricing rules are somewhat different than those present at the time the Commission adopted its *Local Competition Order*. At that time, local competition was largely a theoretical exercise and we placed a premium on the need to stimulate entry into the local exchange market.[6] To the extent that the application of our TELRIC pricing rules distorts our intended pricing signals by understating forward-looking costs, it can thwart one of the central purposes of the Act: the promotion of facilities-based competition.[7]

To this end, a key question concerns whether the efforts of regulators devoted to "getting the prices right" are misplaced. For example, if new entrants make their build-or-buy decisions on the basis of the relative costs of building versus buying regardless of the actual prices for these two options there would be no cause for regulators to be concerned about how accurately the relative prices signal information about the relative costs.

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[2] The express purpose of the 1996 Telecommunications Act was "To promote competition and reduce regulation in order to secure lower prices and higher quality services for American telecommunications consumers and encourage the rapid deployment of new telecommunications technologies." Preamble, Telecommunications Act of 1996, P. L. No. 104–104, 110 Stat. 56 (1996).

[3] See, for example, FCC (1996), Kahn et al. (1999), Kaserman and Mayo (1999) and Weisman (2000) for a discussion of these issues. See the September 2002 special issue of *The Review of Network Economics* for a series of articles that examine the Supreme Court's review of the FCC's costing methodology for the pricing of network elements. For a comprehensive review of the access pricing literature, see Armstrong (2002) and Vogelsang (2003).

[4] The FCC employed a "necessary and impair" standard rather than an essential facilities standard for determining the scope of the unbundling obligations imposed on incumbent providers. See FCC (2003a, para 55–191). An essential facility exhibits three basic characteristics: it is necessary for production of the retail service (e.g., basic telephone service), it is monopoly provided and it cannot be economically duplicated or self-supplied by a competitor. For a comprehensive analysis of the essential facilities doctrine, see Lipsky and Sidak (1999). Technically speaking, when the network element is an essential facility, there is no make-or-buy decision *per se*, since by definition the input cannot be economically duplicated.

[5] The FCC (2005, para 220) continued this line of thinking when it removed mass market switching as an unbundled network element, in part, because TELRIC-based prices for switching discouraged investment in facilities-based networks.

[6] FCC (2003b) at Sect. 2.

[7] FCC (2003b) at Sect. 3.

This issue is highlighted in a recent article by Sappington (2005), who uses a Hotelling model of competition to demonstrate that market entrants will make or buy an input required for downstream production on the basis of a comparison between their cost and the incumbent's cost of making the input instead of a comparison between their cost and the price at which the input can be purchased from the incumbent. In other words, the actual level of input prices is irrelevant. This result has potentially far-reaching economic and public policy implications because it would serve to render this debate over the proper level of input prices largely moot. In other words, regulators should perhaps devote their time and effort to other pursuits.

We examine whether this important finding concerning the irrelevance of input prices is a general result, or is sensitive to the particular model of competition employed. We find that whether input prices are indeed irrelevant depends upon the particular model of downstream competition.[8] Specifically, taking the Hotelling model as a starting point, we demonstrate a continuum of findings in which input prices are irrelevant, may not be irrelevant and are not irrelevant in the case of Hotelling, vertical differentiation Bertrand and Cournot competition, respectively.

These theoretical results would appear to be consistent with a growing body of empirical research that suggests that input prices do influence the entrant's make-or-buy decision.[9,10] In other words, departures from cost-based input prices may distort entrants' make-or-buy decisions in settings of practical interest.[11] Moreover, unless policymakers can be certain that the Hotelling model characterizes competitive behavior in local telecommunications markets, setting input prices to reflect costs accurately is necessary to ensure that there is no efficiency distortion in the build-or-buy decision.

The format for the remainder of this paper is as follows. After outlining the basic assumptions and definitions in Sect. 2, we review the key finding from the Hotelling model concerning the irrelevance of input prices in Sect. 3. Sects. 4 and 5 examine whether the key result on input price irrelevance holds, more generally, in the Bertrand vertical differentiation model and a simple Cournot model, respectively. Section 6 summarizes the key findings, discusses their policy significance and concludes. The proofs of all propositions are in the Appendix.

8 Notably, Sappington (2005, p. 1636) observes that future research should consider alternative models of downstream competition.

9 See, for example, Crandall et al. (2004) and Eisner and Lehman (2001). In addition, Hazlett (2005) contends that mandatory network sharing has had the effect of reducing rather than stimulating facilities-based investment.

10 In addition, Hazlett and Havener (2003, p. 447) report that the share prices of the narrowband equipment manufacturers, including Lucent and Nortel, declined upon announcement that the FCC was liberalizing unbundling rules, essentially lowering the price of the buy option. This pattern of returns may indicate that the market perceived that a reduction in the price of the buy option would increase demand for buying the input and concomitantly reduce the demand for making the input, *ceteris paribus*.

11 It should be noted that Sappington briefly considers model extensions in which input prices may not be irrelevant, but this is not the focus of his analysis nor does it appear to be the basis for his main policy conclusion that "regulators may have substantial flexibility to structure input prices to achieve other important social goals, while ensuring efficient make-or-buy decisions" (2005, p. 1636). Indeed, our findings suggest that it is no less plausible to believe that regulators do not have such discretion.

2 Assumptions and definitions

Each unit of downstream output requires one unit of the upstream input and one unit of the downstream input. Each firm supplies its own downstream input. The incumbent's constant unit cost of producing downstream input is denoted by c_d^I. The corresponding unit cost for the entrant is denoted by c_d^E. The incumbent and entrant's constant unit cost of producing the upstream input are denoted by c_u^I and c_u^E, respectively. π_M^E and π_B^E denote the entrant's profits when it makes the input and buys the input, respectively. The timing in each of the models we develop is identical to that of Sappington (2005, pp. 1632–1633).

The provisions of the 1996 Telecommunications Act provide entrants with the option of purchasing the upstream input from the incumbent at prices determined by state regulators. Let w denote the price the entrant pays the incumbent for buying the upstream input. The entrant is understood to make the efficient make-or-buy decision if it purchases the input from the incumbent when the incumbent is the least-cost supplier ($c_u^I < c_u^E$) and produces the input itself whenever it is the least-cost supplier ($c_u^I > c_u^E$).

3 Hotelling model

Sappington (2005) uses the standard Hotelling model of price competition with differentiated products to evaluate the entrant's make-or-buy decision.[12] His main finding is stated in Proposition 1:

Proposition 1 (**Sappington**) *Regardless of the established price (w) of the upstream input: (a) the entrant prefers to buy the upstream input from the incumbent when the incumbent is the least-cost supplier of the input (i.e., $\pi_B^E > \pi_M^E$ if $c_u^I < c_u^E$); and (b) the entrant prefers to make the upstream input itself when it is the least-cost supplier of the input (i.e., $\pi_M^E > \pi_B^E$ if $c_u^E < c_u^I$).*

Proposition 1 reveals that, within the Hotelling framework, the entrant always makes the efficient make-or-buy decision regardless of the level of the input price, w. This is the basis for the claim that input prices are irrelevant for the entrant's make-or-buy decision.

Sappington's analysis of the Hotelling model emphasizes an important result that was first recognized and derived in a pioneering article by Chen (2001). In a more general setting, Chen shows that a downstream firm (in this case the entrant) may strategically decide to purchase an input from a vertically integrated firm (in this case the incumbent) in an effort to soften downstream competition. The main idea is that a vertically-integrated firm will be less aggressive downstream when its upstream profitability is directly linked to downstream rivals' demand for its upstream input. This strategic effect dominates the entrant's make-or-buy decision in the standard Hotelling framework. However, in the following Bertrand vertical differentiation model, we

[12] See Sappington (2005, pp. 1632–1633) and Tirole (1989, pp. 97–99) for the general structure and assumptions underlying this model.

show that this strategic effect does not dominate the entrant's make-or-buy decision for all values of w.

4 Bertrand vertical differentiation model

The following is a simple quality differentiation model, where we assume that the incumbent produces the high quality good and the entrant produces a lower quality substitute good. In similar fashion to the standard Hotelling framework, we assume that a consumer requires only one unit of the product. A consumer's indirect utility for the high quality good is given by, $V_h = \theta\lambda_h - p_h$, while her indirect utility for the low quality good is given by $V_l = \theta\lambda_l - p_l$, where $\lambda_h > \lambda_l$.[13] Each consumer has a unique θ, which captures taste heterogeneity in the population and is assumed to be uniformly distributed on the interval [0, 1].

We begin with three observations. First, note that $V_h > V_l$ for any $\theta \in (0, 1]$ if $p_l = p_h$, which implies that good h is of higher quality relative to good l and we must have $p_l < p_h$ if any consumers are to find good l more attractive than good h. Second, the consumer with utility $\theta\lambda_l - p_l = 0$ is indifferent between buying and not buying and has taste parameter, $\tilde{\theta} = p_l/\lambda_l$. Third, a consumer that is indifferent between the high and low quality product must have a $\hat{\theta}$ such that $\hat{\theta}\lambda_h - p_h = \hat{\theta}\lambda_l - p_l$, which implies that $\hat{\theta} = (p_h - p_l)/(\lambda_h - \lambda_l)$.

Without loss of generality, normalize the population of consumers to 1. As such, demand for the low quality product is $Q_l = \hat{\theta} - \tilde{\theta}$, while demand for the high quality product is $Q_h = 1 - \hat{\theta}$. The demand functions are therefore given by:

$$Q_l = \frac{p_h}{(\lambda_h - \lambda_l)} - \frac{\lambda_h p_l}{(\lambda_h - \lambda_l)\lambda_l}; \text{ and } Q_h = 1 - \frac{p_h - p_l}{(\lambda_h - \lambda_l)}.$$

The following proposition shows that when the entrant is (not) the least-cost supplier, its make-or-buy decision is (not) independent of input prices in a Bertrand framework.

Proposition 2 *In the equilibrium of the Bertrand vertical differentiation model: (a) The entrant makes the input rather than buys from the incumbent when* $c_u^E < c_u^I$ *for* $w \geq c_u^E$*; and (b) The entrant buys the input from the incumbent if and only if* $c_u^E > c_u^I$ *and* $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) < \lambda_l(w - c_u^I)$.[14,15]

[13] λ_h and λ_l can be interpreted as measures of the consumers' perception of quality that might simply be based on greater familiarity with the incumbent's product vis-à-vis the entrant's product.

[14] It is readily shown that $w < c_u^E$ is a sufficient, but not a necessary, condition for part (b). See the proof of Proposition 2, case 2 in the Appendix.

[15] It should be noted that Proposition 2 can also be derived from a simple Bertrand model with linear demands, where the demand functions are specified as $Q_l = \alpha - \lambda_h P_l + \lambda_l P_h$ and $Q_h = \alpha - \lambda_h P_h + \lambda_l P_l$. In other words, the assumptions that products are differentiated along quality lines and that each consumer requires only one unit of the product can be relaxed and we would still obtain the same qualitative results as in Proposition 2. In addition, the qualitative results in Proposition 2 still hold if we make the incumbent the supplier of the low quality product and the entrant the supplier of the high quality product.

Proposition 2 reveals that the entrant will still choose to make the input when $c_u^E > c_u^I$ and $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) > \lambda_l(w - c_u^I)$. Since the second inequality can be expressed as $w > ((2\lambda_h - \lambda_l)\, c_u^E - \lambda_l c_u^I)/2\,(\lambda_h - \lambda_l)$, for w sufficiently large the entrant will make the input rather than buy the input even though this is not an efficient outcome. It follows that under the specified conditions, the input price is not irrelevant for the entrant's make-or-buy decision. This occurs because for w sufficiently large it is more profitable for the entrant to reduce its cost by making the input instead of softening downstream competition by purchasing the input from the incumbent.[16]

5 Cournot model

The Cournot model of competition has been used extensively in the literature on sabotage (nonprice discrimination).[17] As the incentives for the incumbent to engage in sabotage typically depend upon the level of w, it is instructive to examine whether input prices are irrelevant in this framework. Hence, let inverse market demand be given by $P(Q) = A - BQ$, where $A > 0$, $B > 0$ and $Q = Q^I + Q^E$ is market output, where Q^I and Q^E denote the incumbent and the entrant's output, respectively.

The following proposition shows that input prices are not irrelevant for the make-or-buy decision in a Cournot framework.

Proposition 3 *In the equilibrium of the Cournot model: (a) The entrant makes the input rather than buys the input from the incumbent when $c_u^E < w$; and (b) The entrant buys the input from the incumbent when $c_u^E > w$.*

Proposition 3 reveals that the entrant will make the make-or-buy decision on the basis of a comparison of the input price, w, with its own constant unit cost of making the input, c_u^E. The strategic effect present in the Hotelling and vertical differentiation Bertrand models, wherein the entrant may buy from the incumbent in order to soften downstream competition, does not arise in the Cournot setting because the incumbent takes the entrant's output as given.[18] Hence, for any $w \neq c_u^I$ there is a potential efficiency distortion in the make-or-by decision and hence input prices are not irrelevant.

6 Conclusion

The primary objective of this paper is to examine whether input prices are irrelevant for the entrant's make-or-buy decision. We find that whether input prices are irrelevant depends upon the particular model of downstream competition. Specifically, while input prices are irrelevant in the Hotelling model of price competition, they are not necessarily irrelevant in the vertical differentiation Bertrand model and are not irrelevant in the Cournot model.

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[16] A numerical example of the results in Proposition 2 is presented in the Appendix.

[17] See, for example, Weisman and Kang (2001) and Mandy (2000) for a survey of this literature.

[18] This corresponds to the limiting case in which a one unit increase in the incumbent's retail sales causes no displacement in the entrant's retail sales, or $\alpha \to 0$ in Sappington's terminology (2005, p. 1636).

These results appear to be consistent with a growing body of empirical research that suggests that input prices do matter for the make-or-buy decision.[19] This empirical research provides some support for the proposition that firm behavior, at least in telecommunications markets, is more likely to be characterized by the vertical differentiation Bertrand or Cournot models than by the Hotelling model. Furthermore, while regulators may choose to depart from cost-based input prices to pursue a variety of public policy objectives, our findings suggest that such departures may distort entrants' make-or-buy decisions in settings of practical interest. In other words, regulators may not be able to depart from cost-based prices with impunity.

In terms of future research, there are two avenues that would seem to hold particular promise. First, given the differences that arise in a price-setting vis-à-vis a quantity-setting framework, it would be instructive to explore the particular setting that best characterizes firm behavior in industries subject to unbundling policies. Second, this line of research would benefit from a more general modeling framework as opposed to the rather specialized models that we employ in this paper and that Sappington employs in his article.

Appendix

Proof of Proposition 1

See Sappington (2005).

Proof of Proposition 2

Case 1 The Entrant Buys the Input from the Incumbent:
The profit functions are given by:

$$\pi_h^B = (p_h - c_d^I - c_u^I)\left(1 - \frac{p_h - p_l}{(\lambda_h - \lambda_l)}\right) + (w - c_u^I)\left(\frac{p_h}{(\lambda_h - \lambda_l)} - \frac{\lambda_h p_l}{(\lambda_h - \lambda_l)\lambda_l}\right) \tag{A1}$$

$$\pi_l^B = (p_l - w - c_d^E)\left(\frac{p_h}{(\lambda_h - \lambda_l)} - \frac{\lambda_h p_l}{(\lambda_h - \lambda_l)\lambda_l}\right). \tag{A2}$$

The first-order conditions with respect to p_h and p_l are given by:

$$\frac{p_l - 2p_h + w + \lambda_h - \lambda_l + c_d^I}{(\lambda_h - \lambda_l)} = 0 \tag{A3}$$

[19] See note 9 *supra*.

$$\frac{2p_l\lambda_h - p_h\lambda_l - w\lambda_h - \lambda_h c_d^E}{(\lambda_l - \lambda_h)\lambda_l} = 0\,. \tag{A4}$$

Solving (A3) and (A4) simultaneously yields the Nash prices:

$$p_h = \frac{\lambda_h(2(\lambda_h - \lambda_l) + 3w + 2c_d^I + c_d^E)}{4\lambda_h - \lambda_l} \tag{A5}$$

$$p_l = \frac{\lambda_l(\lambda_h - \lambda_l) + 2\lambda_h c_d^E + \lambda_l c_d^I + w(2\lambda_h + \lambda_l)}{4\lambda_h - \lambda_l}\,. \tag{A6}$$

Substituting (A5) and (A6) into the demand function for the low quality product yields:

$$Q_l^B = \frac{\lambda_h(2w\lambda_l - 2w\lambda_h + \lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - \lambda_l^2)}{\lambda_l(\lambda_l - \lambda_h)(\lambda_l - 4\lambda_h)}\,. \tag{A7}$$

Since $\lambda_h > \lambda_l$, $Q_l^B \geq 0$ requires the numerator in (A7) to be nonnegative or $(2w\lambda_l - 2w\lambda_h + \lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - \lambda_l^2) \geq 0$.
Substituting (A5) and (A6) into (A2) yields the entrant's reduced form profit function:

$$\pi_l^B = \frac{\lambda_h(2w\lambda_l - 2w\lambda_h + \lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - \lambda_l^2)^2}{\lambda_l(\lambda_h - \lambda_l)(\lambda_l - 4\lambda_h)^2}\,. \tag{A8}$$

$Q_l^B \geq 0$ implies that the expression inside the parentheses of the numerator in (A8) is nonnegative.
Case 2 The Entrant Makes the Input:
The profit functions are given by:

$$\pi_h^M = (p_h - c_d^I - c_u^I)\left(1 - \frac{p_h - p_l}{(\lambda_h - \lambda_l)}\right) \tag{A9}$$

$$\pi_l^M = (p_l - c_u^E - c_d^E)\left(\frac{p_h}{(\lambda_h - \lambda_l)} - \frac{\lambda_h p_l}{(\lambda_h - \lambda_l)\lambda_l}\right). \tag{A10}$$

The first-order conditions with respect to p_h and p_l are given by:

$$\frac{p_l - 2p_h + \lambda_h - \lambda_l + c_d^I + c_u^I}{(\lambda_h - \lambda_l)} = 0 \tag{A11}$$

$$\frac{-2p_l\lambda_h + p_h\lambda_l + \lambda_h c_d^E + \lambda_h c_u^E}{\lambda_l(\lambda_h - \lambda_l)} = 0\,. \tag{A12}$$

Solving (A11) and (A12) simultaneously yields the Nash prices:

$$p_h = \frac{\lambda_h(2(\lambda_h - \lambda_l) + 2c_d^I + c_d^E + 2c_u^I + c_u^E)}{4\lambda_h - \lambda_l} \tag{A13}$$

$$p_l = \frac{\lambda_l(\lambda_h - \lambda_l) + 2\lambda_h c_d^E + \lambda_l c_d^I + 2\lambda_h c_u^E + \lambda_l c_u^I}{4\lambda_h - \lambda_l}. \tag{A14}$$

Substituting (A13) and (A14) into the demand function for the low quality product yields:

$$Q_l^M = \frac{\lambda_h(\lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - 2\lambda_h c_u^E + \lambda_l c_u^I + \lambda_l c_u^E - \lambda_l^2)}{\lambda_l(\lambda_l - \lambda_h)(\lambda_l - 4\lambda_h)}. \tag{A15}$$

Since $\lambda_h > \lambda_l$, $Q_l^M \geq 0$ requires the numerator in (A15) to be nonnegative or $(\lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - 2\lambda_h c_u^E + \lambda_l c_u^I + \lambda_l c_u^E - \lambda_l^2) \geq 0$.
Substituting (A13) and (A14) into (A10) yields the entrant's reduced form profit function:

$$\pi_l^M = \frac{\lambda_h(\lambda_h\lambda_l - 2\lambda_h c_d^E + \lambda_l c_d^I + \lambda_l c_d^E - 2\lambda_h c_u^E + \lambda_l c_u^I + \lambda_l c_u^E - \lambda_l^2)^2}{\lambda_l(\lambda_h - \lambda_l)(\lambda_l - 4\lambda_h)^2}. \tag{A16}$$

$Q_l^M \geq 0$ implies that the expression inside the parentheses of the numerator in (A16) is nonnegative.

Comparing (A8) and (A16) reveals that $\pi_l^B > \pi_l^M$ if and only if $(2\lambda_h - \lambda_l)(w - c_u^E) < \lambda_l(w - c_u^I)$. Also, $(2\lambda_h - \lambda_l) > \lambda_l$ since $\lambda_h > \lambda_l$. This implies that $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) > \lambda_l(w - c_u^I)$ for any $w \geq c_u^E$ when $c_u^E < c_u^I$ which establishes part (a). Note that in the case where $c_u^E < c_u^I \leq w$ the inequality holds because $(2\lambda_h - \lambda_l) > \lambda_l$ and $(w - c_u^E) > (w - c_u^I) \geq 0$, which implies that the left-hand side of the inequality exceeds the right-hand side of the inequality. The inequality holds in the case where $c_u^E \leq w < c_u^I$ because the left-hand side is nonnegative while the right-hand side is negative. Finally, if $c_u^E > c_u^I$, then $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) < \lambda_l(w - c_u^I)$ for w sufficiently small. To see this, observe that $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) < \lambda_l(w - c_u^I)$ $\Rightarrow w < ((2\lambda_h - \lambda_l)\, c_u^E - \lambda_l c_u^I)/2\,(\lambda_h - \lambda_l)$. Furthermore, since $c_u^E > c_u^I$ and $(2\lambda_h - \lambda_l) > \lambda_l > 0$, a sufficient condition for $(2\lambda_h - \lambda_l)\left(w - c_u^E\right) < \lambda_l(w - c_u^I)$ is $w < c_u^E = \frac{2(\lambda_h - \lambda_l)c_u^E}{2(\lambda_h - \lambda_l)} < \frac{(2\lambda_h - \lambda_l)c_u^E - \lambda_l c_u^I}{2(\lambda_h - \lambda_l)}$. This establishes part (b).

Numerical example

The following is a numerical example that is used to verify Proposition 2. The assumed parameter values are shown in Table A1.

Table A1 Parameter values used for numerical example

λ_h	λ_l	c_d^I	c_u^I	c_d^E	c_u^E
5	3	0.3	0.2	0.6	0.4

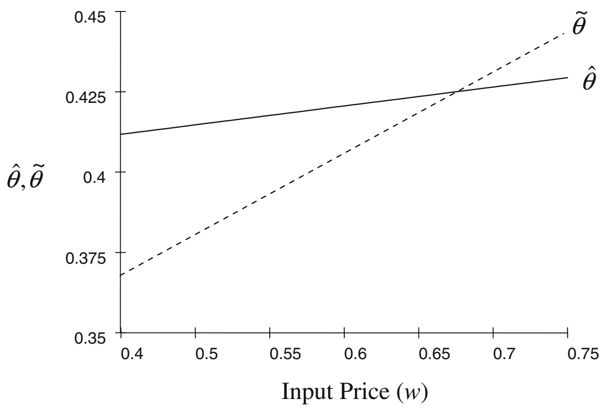

Fig. 1 $\hat{\theta}$ and $\tilde{\theta}$ as a function of input price

Figure 1 plots $\hat{\theta}$ and $\tilde{\theta}$ as a function of the input price, w, assuming that the entrant buys the input from the incumbent. First, since $Q_l = \hat{\theta} - \tilde{\theta}$, for $Q_l > 0$ we require that $\hat{\theta} > \tilde{\theta}$.

From Fig. 1, this condition is satisfied for $w \in (0.4,\ 0.675)$. Second, since $Q_h = 1 - \hat{\theta}$, from Fig. 1 we can also see that $Q_h > 0$ for $w \in (0.4,\ 0.675)$. Thus we have a unique interior Nash equilibrium for any $w \in (0.4,\ 0.675)$. In summary, $\tilde{\theta} > 0$, $\hat{\theta} < 1$ and $\hat{\theta} > \tilde{\theta}$ for any $w \in (0.4,\ 0.675)$ when the entrant buys the upstream input from the incumbent, while $\tilde{\theta} = 0.343$ and $\hat{\theta} = 0.368$ in the case where the entrant makes the upstream input.

Figure 2 plots the entrant's reduced-form profit functions, corresponding to Eqs. (A8) and (A16), with respect to the input price, w. Note that the π_l^B curve is above the π_l^M curve for $w \in (0.4,\ 0.55)$. The opposite is true for $w \in (0.55,\ 0.675)$. This implies that the entrant will buy the input from the incumbent whenever $w \in (0.4,\ 0.55)$, otherwise the entrant will choose to make the input.

From part (b) of proposition 2, the entrant will buy the input from the incumbent as long as $w < ((2\lambda_h - \lambda_l)\, c_u^E - \lambda_l c_u^I)/2\,(\lambda_h - \lambda_l)$. If we substitute the parameter values from Table A1 into the right-hand side of this inequality, we can verify that $\left((2\lambda_h - \lambda_l)\, c_u^E - \lambda_l c_u^I\right)/2(\lambda_h - \lambda_l) = 0.55$.

Figure 3 plots the entrant's reduced-form profit functions, Eqs. (A8) and (A16), with respect to the input price, w. The only difference between Figs. 2 and 3 is the assumed parameter value for the entrant's marginal cost for producing the upstream input, c_u^E. In Fig. 2 $c_u^E = 0.4$ while in Figure 3 $c_u^E = 0.19$. Since the incumbent's marginal cost for producing the upstream input is $c_u^I = 0.2$, then the important distinction between Figs. 2 and 3 is that in Fig. 2 $c_u^E > c_u^I$ while $c_u^E < c_u^I$ in Fig. 3.

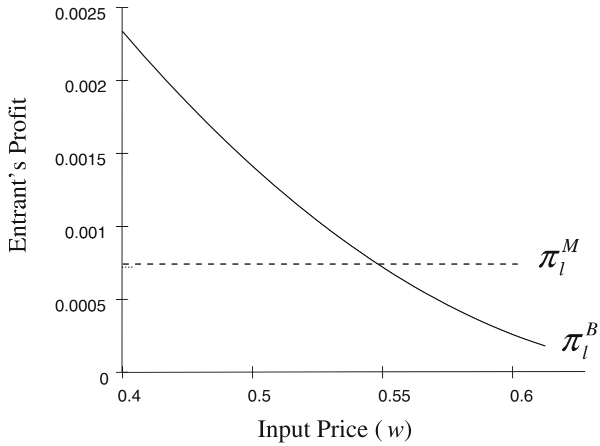

Fig. 2 Entrant's reduced-form profit as a function of input price when $c_u^E > c_u^I$

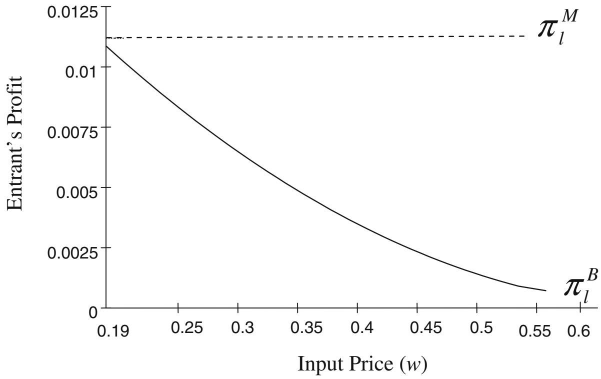

Fig. 3 Entrant's reduced-form profit as a function of input price when $c_u^E < c_u^I$

Note that lowering the assumed value for c_u^E does not affect the entrant's π_l^B curve, but it does serve to shift the entrant's π_l^M curve upwards. Since the π_l^B curve never intersects the π_l^M curve in Fig. 3, the entrant will choose to make the input rather than purchase it from the incumbent for any $w \in (0.19,\ 0.675)$. Thus, part (a) of Proposition 2 is verified. For the equilibrium in Fig. 3, $\tilde{\theta} = 0.302$ and $\hat{\theta} = 0.399$. In summary, the numerical analysis shows that all the results in Proposition 2 can occur while maintaining that $\tilde{\theta} > 0$, $\hat{\theta} < 1$ and $\hat{\theta} > \tilde{\theta}$.

Proof of Proposition 3

Case 1 The entrant buys the input from the incumbent:
The profit functions for the incumbent and entrant are given, respectively, by

$$\pi^I = [w - c_u^I]Q^E + [P(Q) - c_u^I - c_d^I]Q^I \text{ and} \tag{A17}$$

$$\pi^E = [P(Q) - w - c_d^E]Q^E. \tag{A18}$$

The first-order conditions with respect to Q^I and Q^E for $P(Q) = A - BQ$ are given by:

$$A - 2BQ^I - BQ^E - c_u^I - c_d^I = 0 \tag{A19}$$

$$A - 2BQ^E - BQ^I - w - c_d^E = 0. \tag{A20}$$

Solving (A19) and (A20) simultaneously yields the Nash outputs:

$$Q^I = \frac{[A - 2(c_u^I + c_d^I) + (w + c_d^E)]}{3B} \tag{A21}$$

$$Q^E = \frac{[A - 2(w + c_d^E) + c_u^I + c_d^I]}{3B}. \tag{A22}$$

$Q^E \geq 0$ implies that $A - 2(w + c_d^E) + c_u^I + c_d^I \geq 0$ in the numerator of (A22). Substituting (A21) and (A22) into $P(Q) = A - BQ$ yields:

$$P(Q) = \frac{[A + (w + c_d^E) + c_u^I + c_d^I]}{3}. \tag{A23}$$

Substituting (A22) and (A23) into (A18) yields the entrant's reduced-form profit function:

$$\pi^E = \frac{[A - 2(w + c_d^E) + c_u^I + c_d^I]^2}{9B}. \tag{A24}$$

$Q^E \geq 0$ implies that the term in braces in the numerator of (A24) is nonnegative.

Case 2 Entrant makes the input:
The analysis for Case 2 is similar to Case 1 with the one exception that c_u^E replaces w:

$$\pi^E = \frac{[A - 2(c_u^E + c_d^E) + c_u^I + c_d^I]^2}{9B}. \tag{A25}$$

Comparing (A25) and (A24) completes the proof of Proposition 3.

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