Letter

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Input Prices and Product Differentiation

DOI 10.1515/bejeap-2016-0015

Published online June 25, 2016

Abstract: In this paper, we study how input prices affect product differentiation in network industries. In particular, we study whether the principle of vertical differentiation (Choi and Shin 1992, “A Comment on a Model of Vertical Product Differentiation.” *The Journal of Industrial Economics* 40 (2):229–31; Wauthy 1996, “Quality Choice in Models of Vertical Differentiation.” *The Journal of Industrial Economics* 44 (3):345–53) remains valid when an entrant purchases an essential input from an incumbent at a regulated price. We find that the higher quality firm always chooses the best available quality, whereas the lower quality firm chooses an intermediate quality, which increases with the input price. If the higher quality firm is the incumbent, a cost-oriented input price maximizes welfare, but comes at the cost of a lower average quality, a higher degree of product differentiation, and therefore stronger downstream market power.

Keywords: access regulation, network industries, vertical differentiation

JEL Classification: L13, L51, L90

1 Introduction

Access regulation plays a key role in the development of competition in network industries. Indeed, in post, telecommunications, energy, railway, etc., incumbents usually own essential infrastructures that cannot be replicated and are required to provide entrants with an access to these infrastructures at a regulated price. Although it facilitates entry, access regulation has been criticized for limiting the entrants’ quality of service. The fact that entrants do not have their own integrated network infrastructures may actually lessen their ability to offer quality improvements.

However, quality of service is not only a matter of technical feasibility, but also of firms’ strategies. Surprisingly, the impact of access regulation on differentiation

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strategies has never been studied in the literature, unlike its effects on prices and investment that are well documented (see Briglauer, Fröbing, and Vogelsang 2015 for a survey).

In this paper, we study whether the principle of vertical differentiation remains valid when an entrant purchases an essential input from an incumbent. Like Choi and Shin (1992) and Wauthy (1996), we find that the higher quality firm always chooses the best available quality, whereas the lower quality firm chooses an intermediate quality. In addition, we find that this intermediate quality increases with the input price and tends towards the quality of the higher quality firm if the input price tends towards its maximum value (i. e. the value such that the market is foreclosed by the incumbent). If the higher quality firm is the incumbent, a cost-oriented input price maximizes welfare, but comes at the cost of a lower average quality, a greater degree of product differentiation, and therefore stronger downstream market power.

2 The Model

An incumbent I and an entrant E compete in prices for final consumers, who buy a product or subscribe to a service from either of the two firms. A consumer θ who buys from firm $i \in \{I, E\}$ derives utility $u_i = \theta s_i - p_i$, where s_i and p_i are the quality and the downstream price set by firm i , respectively. Parameter θ represents the consumer's preference for quality. It is assumed to be uniformly distributed between 0 and θ^+ .¹ We consider that the incumbent is the higher quality firm, i. e. that $s_E < s_I$.² Then, the demand functions are $q_I = (\theta^+ - \theta_I)/\theta^+$ and $q_E = (\theta_I - \theta_E)/\theta^+$, where θ_I is such that $u_I = u_E$ and θ_E such that $u_E = 0$. From the utility functions, we find $\theta_I = (p_I - p_E)/(s_I - s_E)$ and $\theta_E = p_E/s_E$.

The incumbent provides the entrant with an essential input at a regulated, linear price u . There are no production costs. The profits of the entrant and the incumbent are

1 The assumption that $\theta = 0$ for the consumer with the lowest preference for quality ensures that the market is never covered, unless the downstream prices are zero. As an extension of Sappington (2005)'s "irrelevance" result, it can be easily proved that the firms' differentiation strategies would not be affected by the input price if the market were covered.

2 The analysis can be reproduced with minor changes for the case where the entrant is the higher quality firm. Then, the entrant always chooses the best available quality, whereas the incumbent chooses an intermediate quality, which increases with the input price.

$$\pi_E = (p_E - u)q_E \quad [1]$$

and

$$\pi_I = (p_I - u)q_I + u(q_I + q_E), \quad [2]$$

respectively.³

The firms and a regulatory authority play a three-stage game. In the first stage, the regulatory authority sets the socially optimal input price. In the second stage, the firms choose their qualities simultaneously. In the third stage, they simultaneously set the downstream prices.

3 Equilibrium Downstream Prices

In this section, we derive the equilibrium downstream prices and study how they are affected by the input price and the qualities.

The equilibrium prices satisfy the first-order conditions

$$q_E + (p_E - u) \frac{\partial q_E}{\partial p_E} = 0 \quad [3]$$

and

$$q_I + (p_I - u) \frac{\partial q_I}{\partial p_I} + u \left(\frac{\partial q_I}{\partial p_I} + \frac{\partial q_E}{\partial p_I} \right) = 0. \quad [4]$$

From the definition of the demand functions, $\partial q_I / \partial p_I = -\partial q_E / \partial p_I$. Therefore, eq. [4] can be written as

$$q_I + (p_I - u) \frac{\partial q_I}{\partial p_I} = 0. \quad [5]$$

The equilibrium prices are explicitly defined as

$$p_E^* = \frac{(s_I - s_E)s_E\theta^+ + (2s_I + s_E)u}{4s_I - s_E} \quad [6]$$

and

$$p_I^* = \frac{2(s_I - s_E)\theta^+ + 3u}{4s_I - s_E} s_I. \quad [7]$$

The following result ensues.

³ Equivalently, the profit of the incumbent can be written as $\pi_I = p_I q_I + u q_E$.

Lemma 1: $0 < \frac{\partial p_E^*}{\partial u} < \frac{\partial p_I^*}{\partial u} < 1 \quad \forall u \in [0, \bar{u})$.

Proof: Straightforward from eqs [6] and [7]. □

Lemma 1 states that an increase in the input price leads to higher downstream prices and to a stronger increase in the incumbent's price than in that of the entrant. It also indicates that a higher input price results in a lower downstream markup ($p_i - u$) for both firms.

Equation [3] shows that the price set by the entrant is based on the usual price–quantity tradeoff. Therefore, a higher input price leads the entrant to increase its downstream price, because it raises its marginal cost. Since a decrease in the incumbent's downstream demand is always compensated exactly by an increase in that of the entrant, the incumbent's downstream price has no impact on its upstream profit. The incumbent is therefore faced with the same price–quantity tradeoff as the entrant and would also raise its downstream price if the input price were to increase.

The conclusion that the price of the incumbent increases more than that of the entrant as the input price increases is explained by the fact that the former is the higher quality firm and therefore has a less price sensitive demand.⁴ Finally, the input price represents the firms' downstream marginal cost, and a negative

⁴ The impact of the input price on each firm's equilibrium price can be described as the sum of a direct effect and a strategic effect. Indeed, we can write

$$\frac{\partial p_i^*}{\partial u} = \frac{\partial p_i^{BR}}{\partial u} \mu + \frac{\partial p_i^{BR}}{\partial p_j} \frac{\partial p_j^{BR}}{\partial u} \mu,$$

where $i, j \in \{E, I\}$, $i \neq j$, and $\mu = 1 / (1 - (\partial p_i^{BR} / \partial p_j)(\partial p_j^{BR} / \partial p_i))$.

The first term on the right-hand side is the direct effect, i. e. the impact of u on the best-response price p_i^{BR} times the multiplier μ . The second term on the right-hand side is the strategic effect, i. e. the product of the impact of u on the best-response price p_j^{BR} , the impact of p_j on p_i^{BR} , and the multiplier.

On the one hand, the direct effect is the same for both firms. Indeed, from eqs [3] and [5], $\partial p_E^{BR} / \partial u = \partial p_I^{BR} / \partial u = 1/2$.

On the other hand, the strategic effect is stronger for the incumbent. This is explained by the fact that the incumbent is the higher quality firm and therefore has a less price-sensitive demand. Indeed, from eqs [3] and [5],

$$\frac{\partial p_i^{BR}}{\partial p_j} = - \frac{\partial q_i}{\partial p_j} / \left(2 \frac{\partial q_i}{\partial p_i} \right).$$

Since $\partial q_E / \partial p_I = \partial q_I / \partial p_E$ and $\partial q_E / \partial p_E < \partial q_I / \partial p_I < 0$ from the definition of the demand functions, $0 < \partial p_E^{BR} / \partial p_I < \partial p_I^{BR} / \partial p_E$. It follows that the downstream price of the incumbent increases more than that of the entrant as the input price increases ($0 < \partial p_E^* / \partial u < \partial p_I^* / \partial u$).

relation between firms' marginal cost and their markup is standard in models of price competition with quasi-linear demands.

At the equilibrium prices, the demands of both firms decrease with the input price. We find that the maximum input price is $\bar{u}$ such that the market is foreclosed by the incumbent if $u \geq \bar{u}$. From eqs [6], [7], and the definition of the demand functions, we find

$$\bar{u} = \frac{s_E}{2} \theta^+. \quad [8]$$

In order to derive the qualities chosen by the firms in the second stage of the game, it is necessary to study how qualities affect the downstream prices. The relation between these variables can be summarized as follows.

Lemma 2: $\partial p_I^* / \partial s_I > 0$, $\partial p_E^* / \partial s_I > 0$, and $\partial p_I^* / \partial s_E < 0$. If $s_E \leq \tilde{s}_E(u, s_I) < s_I$, then $\partial p_E^* / \partial s_E \geq 0$. If $\tilde{s}_E(u, s_I) < s_E < s_I$, then $\partial p_E^* / \partial s_E < 0$.

Proof: From eqs [6] and [7], we find

$$\begin{aligned} \frac{\partial p_I^*}{\partial s_I} &= \frac{2(4s_I^2 - 2s_I s_E + s_E^2)\theta^+ - 3us_E}{(4s_I - s_E)^2}, \\ \frac{\partial p_E^*}{\partial s_I} &= \frac{3s_E(s_E\theta^+ - 2u)}{(4s_I - s_E)^2}, \\ \frac{\partial p_I^*}{\partial s_E} &= -\frac{3s_I(2s_I\theta^+ - u)}{(4s_I - s_E)^2}, \end{aligned}$$

and

$$\frac{\partial p_E^*}{\partial s_E} = \frac{6us_I + (4s_I^2 - 8s_I s_E + s_E^2)\theta^+}{(4s_I - s_E)^2}.$$

It follows that $\partial p_I^* / \partial s_I > 0$, $\partial p_E^* / \partial s_I > 0$, and $\partial p_I^* / \partial s_E < 0$. If $s_E \leq \tilde{s}_E(u, s_I)$ where $\tilde{s}_E(u, s_I) = 4s_I - (6s_I\theta^+ (2s_I\theta^+ - u))^{1/2} / \theta^+$, then $\partial p_E^* / \partial s_E \geq 0$. Otherwise, $\partial p_E^* / \partial s_E < 0$. Finally, we find that $\tilde{s}_E(u, s_I) < s_I \quad \forall u \in [0, \bar{u}]$. $\square$

Lemma 2 indicates that an increase in the incumbent's quality would lead both firms to raise their prices, whereas an increase in the entrant's quality would lead the incumbent to lower its price. So would the entrant if its quality is close to that of its rival. Otherwise, it would raise its price.

This result is standard in the literature on vertical differentiation and the contribution of Lemma 2 is to extend it to the case where an entrant purchases an essential input from an incumbent. Fundamentally, the fact that

prices do not change in the same direction when the quality of the incumbent increases and when that of the entrant does is explained by the fact that product differentiation increases in the former case, whereas it decreases in the latter.

4 Equilibrium Qualities

In this section, we solve the second stage of the game and derive the equilibrium qualities.

The impact of a firm's quality on its equilibrium profit $\pi_i^* = \pi_i(p_i^*, p_j^*)$ is twofold. On the one hand, if a firm raises its quality, it has a direct, positive effect on its demand. On the other hand, its rival strategically changes its price, which in turn affects the firm's demand. From the envelope theorem,

$$\frac{\partial \pi_i^*}{\partial s_i} = (p_i^* - u) \left(\frac{\partial q_i}{\partial s_i} \Big|_{p_i^*, p_j^*} + \frac{\partial p_j^*}{\partial s_i} \frac{\partial q_i}{\partial p_j} \Big|_{p_i^*, p_j^*} \right), \quad i, j \in \{E, I\}, i \neq j, \quad [9]$$

where the first term in the second parenthesis represents the direct effect and the second term the strategic effect. The following result ensues.

Proposition 1: For all $u \in [0, \bar{u})$, $\partial \pi_I^* / \partial s_I > 0$. If $s_E \leq s_E^*(u, s_I)$, then $\partial \pi_E^* / \partial s_E \geq 0$. Otherwise, $\partial \pi_E^* / \partial s_E < 0$. $\partial s_E^* / \partial u > 0$, $s_E^*(0, s_I) = 4s_I/7$, and $\lim_{u \rightarrow \bar{u}} s_E^*(u, s_I) = s_I$.

Proof: It follows from the definition of the demand functions that $\partial q_I / \partial s_I > 0$ and $\partial q_I / \partial p_E > 0$. Moreover, from Lemma 2, $\partial p_E^* / \partial s_I > 0$. Therefore, $\partial \pi_I^* / \partial s_I > 0$. From eqs [6], [7], and [9], we find

$$\frac{\partial \pi_E^*}{\partial s_E} = \frac{(8s_I^2 - 6s_I s_E + 4s_E^2)u + (4s_I - 7s_E)s_I s_E \theta^+}{(4s_I - s_E)^3 s_E^2 \theta^+} (s_E \theta^+ - 2u) s_I.$$

Then, we can define

$$s_E^*(u, s_I) = \frac{2s_I^2 \theta^+ - 3us_I + s_I((2s_I \theta^+ - u)(2s_I \theta^+ + 23u))^{1/2}}{(7s_I \theta^+ - 4u)}$$

such that $\partial \pi_E^* / \partial s_E \geq 0$ if $s_E \leq s_E^*(u, s_I)$ and $\partial \pi_E^* / \partial s_E < 0$ otherwise. It is just a matter of computation to show that $\partial s_E^* / \partial u > 0$, $s_E^*(0, s_I) = 4s_I/7$, and $\lim_{u \rightarrow \bar{u}} s_E^*(u, s_I) = s_I$. $\square$

According to Proposition 1, the incumbent always chooses the best available quality $\bar{s}$, whereas the entrant chooses an intermediate quality, which increases with the input price. The equilibrium qualities are

$$s_I^* = \bar{s} \quad [10]$$

and

$$s_E^* = \frac{2\bar{s}^2\theta^+ - 3u\bar{s} + \bar{s}^2((2\bar{s}\theta^+ - u)(2\bar{s}\theta^+ + 23u))^{1/2}}{(7\bar{s}\theta^+ - 4u)}. \quad [11]$$

At a cost-oriented input price ($u = 0$), the entrant's equilibrium quality is $4/7$ of that of the incumbent, as in Choi and Shin (1992) and Wauthy (1996). If the input price tends towards its maximum value, i. e. the value such that the market is foreclosed by the incumbent, then the entrant minimizes differentiation and its quality tends towards that of the incumbent.

Proposition 1 can be explained as follows. If the incumbent raises its quality, the entrant's price increases (Lemma 2). Therefore, the direct and the strategic effects are both positive, and the incumbent always chooses the best available quality. For the entrant, the direct and the strategic effect work in opposite directions, because the incumbent lowers its price if the entrant sets a higher quality (Lemma 2). The direct, positive effect dominates for a high degree of differentiation, whereas the strategic, negative effect dominates for a low degree of differentiation. This explains why the entrant chooses an intermediate quality.

The quality chosen by the entrant increases with the input price for two reasons. First, a higher input price strengthens the direct, positive effect: A higher input price increases the price gap between the incumbent and the entrant (from eqs [6] and [7], $p_I^* - p_E^* > 0$ and $\partial(p_I^* - p_E^*)/\partial u > 0$), which makes the demand more sensitive to changes in qualities. Second, a higher input price weakens the negative, strategic effect. Indeed, the higher the input price, the lower the decrease in the incumbent's price resulting from an increase in the entrant's quality.⁵

⁵ Lemma 2 indicates that $\partial p_I^*/\partial s_E = -3s_I(2s_I\theta^+ - u)/(4s_I - s_E)^2 < 0$. It ensures that $\partial^2 p_I^*/\partial u \partial s_E = 3s_I/(4s_I - s_E) > 0$. This result can be explained as follows. From eq. [5], the impact of s_E on the best-response price of the incumbent p_I^{BR} is given by

$$\frac{\partial p_I^{\text{BR}}}{\partial p_E} = - \left(\frac{\partial q_I}{\partial s_E} + (p_I - u) \frac{\partial^2 q_I}{\partial s_E \partial p_I} \right) / \left(2 \frac{\partial q_I}{\partial p_I} \right).$$

This equation indicates that the price of the incumbent decreases with the quality of the entrant, because the incumbent's demand is a decreasing function of the latter ($\partial q_I/\partial s_E < 0$), and because an increase in the entrant's quality reduces differentiation and exacerbates the price sensitivity of demand ($\partial^2 q_I/\partial s_E \partial p_I < 0$). The higher is the input price, the less important is the latter effect, and therefore the lower is the decrease in the price of the incumbent.

5 Socially Optimal Input Price

In the first stage of the game, a regulatory authority sets the input price which maximizes welfare. The latter is defined as

$$W = \int_{\theta_E^*}^{\theta_I^*} \theta s_E^* d\theta + \int_{\theta_I^*}^{\theta^+} \theta s_I^* d\theta = \frac{S_E^*}{2} (q_E^*)^2 + \frac{S_I^*}{2} (q_I^*)^2, \quad [12]$$

where q_E^* , q_I^* , θ_E^* , and θ_I^* are the demands and the locations of the indifferent consumers evaluated at the equilibrium prices and qualities. The relation between the input price and welfare is summarized by the following proposition.

Proposition 2: $\frac{\partial W}{\partial u} < 0$, $\forall u \in [0, \bar{u})$.

Proof: From eqs [6], [7], [10], [11], and [12], we find

$$\frac{\partial W}{\partial u} = - \frac{1909u^3\bar{s} - u^2(5676\bar{s}^2\theta^+ - 23Z) + 16\bar{s}^2(\theta^+)^2(22\bar{s}^2\theta^+ - 7Z) + 2u\bar{s}\theta^+(1770\bar{s}^2\theta^+ + 41Z)}{288(\theta^+)^3Z^2},$$

where $Z = ((2\bar{s}\theta^+ - u)(2\bar{s}\theta^+ + 23u))^{1/2}\bar{s}$.

It is just a matter of computation to show that $\partial W / \partial u < 0$, $\forall u \in [0, \bar{u})$. $\square$

It ensues from Proposition 2 that the socially optimal input price is the cost-oriented price $u = 0$. This result can be interpreted as follows. An increase in the input price has three effects on welfare. First, it heightens the quality offered by the entrant, which improves welfare. Second, it raises the number of consumers who do not buy the good or subscribe to the service, which reduces welfare. Third, it decreases the market share of the incumbent, which also reduces welfare, because the incumbent is the higher quality firm. Formally,

$$\frac{\partial W}{\partial u} = \frac{(q_E^*)^2}{2} \frac{\partial s_E^*}{\partial u} + (q_I^* s_I^* - q_E^* s_E^*) \frac{\partial q_I^*}{\partial u} - \frac{q_E^* s_E^*}{\theta^+} \frac{\partial \theta_E^*}{\partial u},$$

where the first term on the right-hand side is positive, whereas the second and third terms are negative. Proposition 2 indicates that the negative effects dominate.

6 Conclusion

In this paper, we have studied how input prices affect firms' vertical differentiation strategies when an entrant purchases an essential input from an incumbent. We have found that the higher quality firm always chooses the best available quality, whereas the lower quality firm chooses an intermediate quality, which increases with the input price. Although a cost-oriented input price maximizes welfare if the higher quality firm is the incumbent, it comes at the cost of a lower average quality, a higher degree of product differentiation, and therefore stronger downstream market power.

From a public policy perspective, our most important finding is the fact that the quality of the lower quality firm increases with the input price. First, this result remains valid if the lower quality firm is the incumbent (see footnote 2). Moreover, in most network industries, quality of service is arguably more important than prices.

A central public policy issue that has been omitted in this paper is the impact of input prices on infrastructure investment. There is a broad consensus that low input prices tend to deter investment. An interesting direction for future research would be to study whether this conclusion remains valid when firms' differentiation strategies are taken into account.

Acknowledgment: The author thanks Nicola Cartwright, Germain Gaudin, Justin Johnson, Till Requate, and two anonymous referees for helpful comments and suggestions. The usual disclaimers apply.

References

- Briglaue, Wolfgang, Stefan Frübing, and Ingo Vogelsang. 2015. "The Impact of Alternative Public Policies on the Deployment of New Communications Infrastructure – A Survey." *The Review of Network Economics* 13 (3):227–70.
- Choi, Chong Ju, and Hyun Song Shin. 1992. "A Comment on a Model of Vertical Product Differentiation." *The Journal of Industrial Economics* 40 (2):229–31.
- Sappington, David E. M. 2005. "On the Irrelevance of Input Prices for Make-or-Buy Decisions." *The American Economic Review* 95 (5):1631–8.
- Wauthy, Xavier. 1996. "Quality Choice in Models of Vertical Differentiation." *The Journal of Industrial Economics* 44 (3):345–53.