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Congestion Pricing of Inputs in Vertically Related Markets*

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ABSTRACT

This paper conducts a welfare analysis of a two-part tariff that is applied to the congestion pricing of inputs supplied by a natural monopolist to competitive firms. Firms in a competitive market are assumed to require an input in a fixed proportion to output, and a monopolist with increasing returns to scale technology is assumed to provide the input under a capacity constraint on its facility. Congestion pricing of inputs achieves allocative efficiency by valuing the constrained capacity of the monopolist in accordance with market conditions. This pricing is optimal for both the welfare-maximizing regulator and the profit-maximizing monopolist if it is applied in the form of a uniform price for the input. However, a two-part tariff for the congestion pricing of inputs is optimal if competition in the downstream market is imperfect or if there is demand uncertainty in the market.

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1. INTRODUCTION

In an industry in which naturally monopolistic and competitive activities are vertically related, the issue of how to regulate the prices of competitive firms' access to the facility of a monopolist is a central question in debates on regulatory reform. Access to the facility in the upstream sector is an input that is required by competitive firms to produce output in the downstream sector. Thus, price regulation of access to the monopolist's facility affects competition in the downstream market.

An extensive literature explores the issue of regulating the price of access to monopolists' facilities (Einhorn, 1990; Baumol and Sidak, 1994; Laffont and Tirole, 1994; Vickers, 1995; Armstrong, Doyle and Vickers, 1996; Larson and Lehman, 1997; Armstrong, 1998; Laffont, Rey and Tirole, 1998a, 1998b; Leautier, 2000). This literature typically applies access price regulation to network industries in which an input is required in a fixed proportion to output; examples include telecommunications, electricity, gas and railways. However, the existing literature assumes that the capacity of the facility of the natural monopolist never fails to meet the demand for access. Because the construction of the natural monopolist's facility requires substantial investment and a great deal of time, insufficient capacity in the facility may ration demand for access from downstream firms, and thereby discourage competition in the downstream market.

This paper focuses on the issue of access price regulation in vertically related markets in which the demand for access may exceed the capacity of the natural monopolist's facility. Under the assumption that congestion pricing is applied to the usage of the facility as an allocatively efficient way of rationing, this paper examines whether a two-part tariff is desirable in terms of welfare maximization and profit maximization. When congestion pricing is applied to the usage of a congestible facility owned and operated by a monopolist with increasing returns to scale technology, the issue of whether the monopolist is allowed to apply a two-part tariff to access pricing is particularly important. This is because additional revenue from the fixed access charge is necessary to finance capacity expansion if the revenue from congestion pricing does not meet the cost of capacity expansion. Since a monopolist with constant returns to scale technology earns sufficient revenue from congestion pricing to cover the cost of capacity expansion (Mohring and Harwitz, 1962), monopolists have an incentive to expand congestible facilities (Vickrey, 1971; FERC, 1989, pp. 96–97). However, a monopolist with increasing returns to scale technology requires an additional source of revenue to finance capacity expansion.

Based on the idea that capacity expansion is financed by a combination of the revenue from congestion pricing and the fixed access fee, Vogelsang (2001) investigates price-cap regulation of access to congestible transmission facilities that exhibit increasing returns to scale. Vogelsang can be criticized for applying a two-part tariff to access pricing, which may be less desirable than a uniform price. Indeed, Ordover and Panzar (1982, Proposition 5) prove that a two-part tariff is inferior to a uniform price in terms of both welfare and profits when the inputs purchased by downstream firms from a monopolist with increasing returns to scale are required in a fixed proportion to those firms' outputs.

The paper examines how three types of downstream-market environment affect the desirability of a two-part tariff for an input supplied by the congestible facility of an upstream monopolist. First, it is assumed that the downstream market is perfectly competitive and the demand for the final product is known with certainty. Hence, a proposition of Ordover and Panzar (1982) relating to inputs required in a fixed proportion to output applies in the context of congestion pricing. That is, a two-part tariff is inferior to a uniform price in terms of both welfare maximization and profit maximization. Second, the assumption of perfect competition in the downstream market is replaced by that of Cournot competition, under which each profit-maximizing firm with increasing returns to scale technology determines its output given the outputs of rival firms. Contrary to the result of Ordover and Panzar, a two-part tariff, which combines a uniform congestion price with a fixed access fee, is superior to a uniform price of congestion under imperfect competition. A two-part tariff is also better than a uniform price when demand for the final product is uncertain, unless the objective of the regulator is to maximize social welfare without limiting the profits of the upstream monopolist or unless capacity constraints are always binding.

The paper is organized as follows. Section 2 presents a basic model that assumes perfect competition in the downstream market and no uncertainty in the demand for the final product. A model with imperfect competition is analyzed in Section 3, and a model with uncertain demand is investigated in Section 4. Section 5 presents brief conclusions and some policy implications. The Appendix provides detailed comparative statics and a numerical example.

2. THE MODEL

2.1 The Basic Model

Consider an industry in which n identical firms purchase x units of an input in the upstream market to supply y units of a homogeneous product to consumers in the downstream market. The input is essential in the sense that downstream firms cannot produce output without this input. Examples of this input include access to networks such as electricity and gas distribution, local telecommunications and railway tracks. Without access to these networks, firms cannot compete effectively in downstream markets such as electricity generation, gas supply, long-distance telecommunications and train services. The input is supplied by the monopolized upstream sector, and the final product is supplied by the perfectly competitive downstream sector, which is characterized by the free entry and exit of identical firms operating at the minimum point of a U-shaped average cost curve. The assumption of a U-shaped average cost curve implies that downstream production technology exhibits scale economies if firms operate below the output level associated with the minimum average cost. Integer constraints are ignored, and n is determined by the condition that downstream firms earn zero profits. The purchased input is required in a fixed proportion to the output of the downstream firms; i.e., $x = zy$, where z is a strictly positive constant representing the ratio of the input to the output. This assumption holds in network industries in which access to networks mirrors service levels in the downstream sector and in which downstream firms must use a monopolist's upstream network to supply services.

Congestion occurs when total demand for the input, denoted by X, exceeds the capacity of the facility owned and operated by the upstream monopolist. Networks such as electricity and gas distribution, local telecommunications and railway tracks may be congestible if the demand for access to these networks exceeds their capacity. To efficiently ration the excess demand for the input, congestion pricing is applied in the upstream sector. Given congestion, profit-maximizing downstream firms should pay r per unit of the input, or should pay zr per unit of the output. Since the downstream sector is perfectly competitive, in equilibrium, the price of the final product, denoted by p, should be equal to the sum of zr and the marginal production cost. The second-order condition for profit maximization of the downstream firms is assumed to hold; that is, the marginal cost of production is an increasing function of output. Using congestion pricing to achieve rationing is allocatively efficient because, in equilibrium, consumers who are only willing to pay less than p are rationed, as are downstream firms that have a marginal production cost exceeding $(p - zr)$. The unit price of congestion is endogenously determined by the degree to which the capacity constraint is tightened in the input market; that is, $r > 0$ if the capacity constraint on the congestible facility is binding, and $r = 0$ otherwise. Unlike in the literature on peak-load pricing, no fluctuations in the demand for the input are assumed. Section 4 relaxes this assumption by incorporating stochastic fluctuations in input demand.

Using a congestible facility, the upstream monopolist produces the required input under increasing returns to scale technology, which implies that the upstream sector is a natural monopoly. Total costs in the upstream activity, denoted by C_m, are assumed to be a function of the capacity of the congestible facility that is used to produce the input:

$$C_m = m_0 + mK \tag{1}$$

where K denotes the capacity of the facility owned and operated by the upstream monopolist. The parameters m_0 and m are a fixed cost and the constant marginal cost of the upstream activity, respectively, and both are assumed to be strictly positive. To focus on the effects of congestion pricing on competition in the downstream sector, the cost of operating the facility is assumed to be zero and costs in the upstream sector depend only on the capacity of the facility.

The upstream monopolist can charge downstream firms a simple two-part tariff, comprising a fixed non-negative access fee, e, and a unit price, r, which corresponds to the unit price of congestion. The total revenue of the upstream monopolist is the sum of en and rX. The welfare-maximizing regulator or the profit-maximizing upstream monopolist chooses the optimal values of e and K, while the value of r is determined by the input market. Examples of mechanisms that determine the value of r include an electricity market in Norway where the unit price of congestion is defined as an interregional difference in market clearing prices (Bjorndal and Jornsten, 2001). A sealed-bid auction is another example of a mechanism determining the unit price of congestion for airport time slots (Rassenti, Smith and Bulfin, 1982).

Equilibrium in the final product market is determined by three conditions: (i) downstream firms earn zero profits; (ii) there is no excess demand for the final product; and (iii) the capacity constraint on the facility of the upstream monopolist is binding. These conditions are represented by the following equations, respectively:

$$(p - zr)y(p, r) - C_d[y(p, r)] = e \tag{2}$$

$$n\, y(p, r) - D(p) = 0 \tag{3}$$

and

$$zD(p) = K, \tag{4}$$

where $y(p, r)$ is the supply function of each downstream firm, $C_d(y)$ is the cost function of each downstream firm, and $D(p)$ is the demand curve for the final product. All these functions are assumed to be twice differentiable. It is also assumed that $y_p \equiv (\partial y/\partial p) > 0$, $y_r \equiv (\partial y/\partial r) < 0$, $y_r = -zy_p$, $\partial C_d/\partial y > 0$, $\partial^2 C_d/\partial y^2 > 0$, and $D' \equiv \partial D/\partial p < 0$. The first three follow from the standard properties of competitive firms' profit functions. Total demand for the final product depends only on price; income is ignored. Equation (4) holds because $X = nx = zny = zD(p)$ in equilibrium. Note that if the capacity constraint is not binding, condition (4) is irrelevant to the final product market and equilibrium is determined by only (2) and (3). Ordover and Panzar (1982) assume that there is no binding constraint on capacity.

[Table 1 here]

Comparative-static analysis is conducted to investigate the response of the equilibrium values of p, r, n, y and X to changes in the parameters e and K. The comparative-static results are summarized in Table 1, and the derivation of the partial derivatives in Table 1 is described in Appendix A. When capacity is held constant, an increase in the access fee reduces the congestion price. This is because the number of downstream firms falls following a rise in the access fee. A decrease in total output due to a fall in the number of downstream firms following a rise in the access fee is exactly offset by the increase in total output that is due to an increase in the output of each downstream firm. Thus, total demand for the input, X, which is assumed to equal zny, is not affected by a change in the access fee. Holding the access fee constant, an increase in capacity lowers both the congestion price per unit of output and the final product price by the same amount. Hence, the output of each downstream firm is unaffected. The equilibrium number of firms increases by $1/x$ due to the expansion of capacity by one unit. The increase in capacity by one unit results in a one-unit increase in total demand for the input.

2.2 Welfare Analysis

Based on the comparative-static analysis given in Section 2.1, optimal choices of input two-part tariffs are investigated in the context of different objective functions. The welfare measure is defined as a weighted sum of upstream monopoly profits and the consumer surplus:

$$L = \gamma \int_p D(w)dw + (1-\gamma)(rX + en - mK - m_0) \tag{5}$$

where γ and 1 – γ are the weights on the consumer surplus and monopoly profits, respectively. This formulation makes it possible to consistently analyze the maximization of monopoly profits (γ = 0), Ramsey-type constrained welfare optima (0 < γ < 0.5), and unconstrained welfare maximization (γ = 0.5). Note that, by assumption, since downstream firms earn zero profits, their profits are excluded from the right-hand side of (5).

Assuming a non-negative access fee and available upstream capacity, the results in Table 1 yield the following necessary conditions for an optimum:

$$\frac{\partial L}{\partial e} = (1-\gamma)e\left(\frac{ny_r}{zy^2}\right) \le 0\,; \quad e \ge 0,\, e\frac{\partial L}{\partial e} = 0. \tag{6}$$

$$\frac{\partial L}{\partial K} = r + \frac{e}{zy} - \frac{\Gamma K}{(-D')z^2} - m = 0\,, \tag{7}$$

where $\Gamma \equiv (1-2\gamma)/(1-\gamma)$. The welfare effects of the access fee comprise changes in the both the consumer surplus and upstream monopoly profits. The term associated with the effect of the access fee on the consumer surplus is absent from $\partial L/\partial e$ because the access fee does not affect the price of the final product given a constant amount of capacity. Thus, the welfare effects of the access fee are limited to effects on upstream monopoly profits. This effect is given by $e(\partial n/\partial e)$, which is equal to $e(ny_r)/(zy^2) < 0$. Thus, the access fee reduces welfare. From (6), the optimal access fee is obtained.

PROPOSITION 1. *When there is a perfectly competitive downstream sector and no demand uncertainty for the final product, the optimal access fee is zero.*

PROOF. Since $(1 - \gamma)(ny_r)/(zy^2) < 0$ in $\partial L/\partial e$, only $e = 0$ satisfies the necessary condition, $e(\partial L/\partial e) = 0$ in (6). Q.E.D.

This result is also obtained by Ordover and Panzar (1982, Proposition 5) in the context of production technology with fixed proportions of x and y. As indicated by Ordover and Panzar, if the downstream sector is perfectly competitive and the input is required in a fixed proportion to output, the upstream monopolist could maximize profits simply by inducing the optimal level of r by an appropriate choice of capacity, but could gain nothing from applying a two-part tariff. The well-known Coasian results, that the unit price equals marginal cost ($r = m$) and that profits are extracted via the access fee ($e > 0$), do not apply if the perfectly competitive production technology of downstream firms combines inputs and outputs in fixed proportions.

The necessary condition with respect to K in (7) implies that the congestion price should reflect the marginal capacity cost of the facility. Since $r = m$ for $\gamma = 0.5$, unconstrained welfare maximization requires the lowest congestion price and the maximum capacity of the upstream facility. By contrast, the maximization of monopoly profit requires the highest congestion price and the minimum capacity of the upstream facility. Given the maximization of monopoly profit, the difference between the unit congestion price and the marginal capacity cost relative to the final product price is equal to the product of $1/z$ and the inverse of the price elasticity of the final product: $(r - m)/p = 1/(z\varepsilon)$, where $\varepsilon \equiv -pD'/D$.

3. IMPERFECT COMPETITION IN THE DOWNSTREAM MARKET

In liberalized markets, the introduction of competition is expected to lower product prices, thereby raising allocative efficiency. However, liberalized markets are not necessarily as competitive as might be expected. Examples include the electricity supply industry in some European countries and the United States, where there has been a growing concern about inefficiency due to the market power of some generators who use constrained transmission facilities (Green and Newbery, 1992; Borenstein and Bushnell, 1999). Examples also include the airline industry in the United States, where carriers with access to highly congested airports have market power (Brueckner, 2002).

In this section, the assumption that the downstream market is perfectly competitive is replaced by the assumption that there is Cournot competition in the downstream market. In the Cournot equilibrium, no downstream firm has any incentive to alter its behavior given the output decisions of its rivals. If downstream firms exhibit Cournot behavior, there will be a mark-up on the price of the final product. As suggested by Armstrong, Cowan and Vickers (1994, p. 151), lowering the unit price of the input below its marginal cost may effectively offset the mark-up. In turn, an access fee may be charged to cover upstream expenses.

3.1 The Model with Cournot Competition in the Downstream Market

The downstream firms are assumed to operate at the Cournot equilibrium. As in Section 2, integer constraints are ignored, and n is determined by the condition that each downstream firm earns zero profits. Given the Cournot behavior of the downstream firms, the equilibrium price of the final product exceeds the sum of the congestion payment per unit of output (zr) and the marginal production cost ($\partial C_d/\partial y$) by the amount $y/(-D')$. This mark-up reflects the market power of downstream firms. The second-order condition in the Cournot oligopoly is assumed to hold; i.e., $z/D' + y/D'' < \partial^2 C_d/\partial y^2$. Note that unless D' is independent of the final product price, the equality $y_r = -zy_p$ does not necessarily hold in Cournot competition.

In the Cournot equilibrium, conditions (2), (3) and (4) also hold as in the perfect competition case. However, the responses of the Cournot equilibrium values of p, r, n, y and X to changes in the parameters e and K differ from those in the perfect-competition equilibrium unless D' is independent of the final product price. The comparative-static results in the Cournot equilibrium are summarized in Table 2, and the derivation of the partial derivatives in Table 2 is described in Appendix B. If D' is independent of the final product price, which is the case in a linear demand function, the equality $y_r = -zy_p$ holds. Hence, the response of the Cournot equilibrium values of p, r, n, y and X to a change in the parameter K is the same as that under perfect competition.

[Table 2 here]

Compared with the perfect competition case, the responses of the congestion price, the supply by downstream firms and the number of downstream firms to a change in the access fee when capacity is constant are mitigated by the positive term $D'/[D'+(y_r/z)]$, which is less than unity, in the Cournot equilibrium. This is because, in the Cournot equilibrium, the shift in the total supply curve in the downstream market due to a change in the access fee is smaller than the shift that occurs in the perfect-competition equilibrium. Holding the access fee constant, the effects of a change in capacity on the endogenous variables are ambiguous under Cournot competition. Whether capacity expansion raises firm supply depends on the relative sizes of y_p and y_r. If $zy_p < -y_r$, the expansion of capacity raises firm supply. The relative sizes of the terms $zD' + y_r$ and $n(zy_p + y_r)$ affect whether capacity expansion increases the number of firms. If $n(zy_p + y_r)$ is larger (smaller) than $zD' + y_r$, the expansion of capacity raises (lowers) the number of downstream firms. The number of firms is not affected by the capacity of the upstream facility if $zD' + y_r$ is equal to $n(zy_p + y_r)$.

3.2 Welfare Analysis in Cournot Competition

Using the results in Table 2 of Section 3.1, the optimal input two-part tariffs faced by Cournot oligopolists are investigated under welfare maximization in (5). The necessary condition with respect to the parameter e is:

$$\frac{\partial L}{\partial e} = (1-\gamma)\frac{ny_r}{y^2(zD'+y_r)}(eD'+y^2) \leq 0\,;\, e \geq 0,\, e\frac{\partial L}{\partial e} = 0\,. \tag{8}$$

As in the case of perfect competition, there is no effect of the access fee on the consumer surplus because $\partial p/\partial e = 0$ in Cournot competition. Although in both cases the term $e(\partial n/\partial e)$, which is non-positive, appears on the right-hand side of the necessary condition with respect to e, there is an additional effect of the access fee on upstream profits under Cournot competition, which is given by the term $n + \partial(rX)/\partial e$, which is positive in this case. This positive effect, which does not arise in the case of perfect competition, is taken into account, as is the adverse effect of $\partial n/\partial e$ when the optimal two-part tariff is to be chosen in the case of imperfect competition in the downstream sector.

The solution of (8) yields the following proposition on the optimal choice of input two-part tariff in the Cournot equilibrium:

PROPOSITION 2. *If the downstream market is in the Cournot equilibrium, the optimal access fee is positive.*

PROOF. Suppose that $e = 0$. Then, from (8) and $y_r/(zD'+y_r) > 0$, $\partial L/\partial e > 0$. Thus, the necessary condition for an optimum, $\partial L/\partial e \leq 0$, cannot be satisfied if $e = 0$. Suppose instead that $e > 0$. Then, from (8), $\partial L/\partial e = 0$. Solving $\partial L/\partial e = 0$ yields the optimal access fee, $e = y^2/(-D') > 0$. Thus, the necessary condition for an optimum is satisfied only if e is positive. Q.E.D.

The positive access fee at the optimum in the Cournot equilibrium contrasts with the optimal access fee of zero under perfect competition, as indicated by Proposition 1. In the Cournot equilibrium, there is a mark-up on the final product price because downstream firms can directly affect the final product price by changing the levels of output. This mark-up is given by the term $y/(-D')$, which corresponds to the difference between the final product price and the sum of congestion payments per unit of output and the marginal production cost.

For the input tariff to be optimal in terms of either welfare maximization or profit maximization, the unit price of the input must fall to offset the distortion caused by the mark-up on the final product price. A fall in the upstream monopolist's revenue, which is due to the fall in the unit price of the input, must be offset by the access fee. The access fee generates excess profits for the upstream monopolist, with these profits arising from Cournot competition in the downstream market.

Note that the optimal access fee in the Cournot equilibrium can also be obtained from a model that assumes: (i) that both r and e are parameters to be chosen by either a welfare-maximizing regulator or a profit-maximizing upstream monopolist; (ii) that the capacity constraint is not binding so that congestion pricing is irrelevant to the analysis; and (iii) that the upstream monopolist's total cost depends only on the total demand for access to the upstream facility. These assumptions render the model of this paper equivalent to that of Ordover and Panzar (1982), who only investigate the case of perfect competition with no demand uncertainty. This modified model with Cournot competition is described in Appendix C, which also presents a derivation of the optimal positive access fee.

Using the results in Table 2, the necessary condition with respect to the parameter K under Cournot competition is:

$$\frac{\partial L}{\partial K} = r + e\left[\frac{zD'+y_r - n(zy_p + y_r)}{zy(zD'+y_r)}\right] - m - \left(\frac{K}{-D'z^2}\right)\left(\frac{z(D'-y_p)}{zD'+y_r} - \frac{\gamma}{1-\gamma}\right) = 0\,. \tag{9}$$

From (9), $e = y^2/(-D')$, and $K=zny$, the optimal price of congestion is:

$$r = m + \frac{y(n\Gamma - 1)}{-zD'}\,. \tag{10}$$

Equation (10) implies that for unconstrained welfare to be maximized ($\Gamma = 0$), the unit price of congestion must be lower than the marginal cost of capacity. The unconstrained welfare-optimal two-part tariff in the case of Cournot competition ($r < m$, $e > 0$) differs from the unconstrained welfare-optimal solutions in the case of perfect competition ($r = m$, $e = 0$). If there is more than one Cournot firm, the profit-maximizing upstream monopolist ($\Gamma = 1$) chooses a unit price of congestion that exceeds the marginal cost of capacity. The difference between the unit congestion price and marginal cost of capacity relative to the final product price depends not only on the price elasticity of total demand, but also on the number of downstream firms; that is, $(r - m)/p = (n - 1)/(z\varepsilon n)$.

To illustrate how Cournot competition affects vertically related markets, consider the following example, in which the demand and marginal cost functions are linear. Suppose that $D(p) = a - p$ and that $C_d(y) = c_0 + 0.5by^2$. Each downstream firm is assumed to require one unit of the input to produce one unit of output, so $z = 1$. Then, $y(p, r) = (p - r)/(1 + b)$ and $e = y^2$ for Cournot competition. For perfect competition, $y(p, r) = (p - r)/b$ and $e = 0$. From (2), the equilibrium supply of each Cournot firm is $(2c_0/b)^{0.5}$, which is equal to the equilibrium supply of each competitive firm. While the supply of each competitive firm corresponds to the minimum point of the average cost, where marginal and average costs are equal, each Cournot firm produces at an output level at which average costs are declining. This is because the average cost of each downstream firm exceeds its marginal cost by e/y in the Cournot equilibrium. The optimal access fee in Cournot competition is $2c_0/b$ whether there is unconstrained welfare maximization, constrained welfare maximization or profit maximization.

Compared to the case of perfect competition in which $p = [a + m + (2bc_0)^{0.5}]/2$ and $K = [a - m - (2bc_0)^{0.5}]/2$ in equilibrium, in Cournot competition, the final product price increases by $(2c_0/b)^{0.5}$, and the capacity of the upstream facility is reduced by $(2c_0/b)^{0.5}$ under profit maximization. Under unconstrained welfare maximization, in equilibrium, the final product price is $m + (2bc_0)^{0.5}$ and capacity is $a - m - (2bc_0)^{0.5}$ both when there is perfect competition and when there is Cournot competition. Compared to the case of perfect competition, when $r = m$ in equilibrium, Cournot competition lowers the optimal price of congestion by $(2c_0/b)^{0.5}$ under unconstrained welfare maximization The optimal monopoly price of congestion is $[a + m - (2bc_0)^{0.5}]/2$ regardless of whether there is perfect competition or Cournot competition.

4. EFFECTS OF UNCERTAINTY IN DEMAND FOR THE FINAL PRODUCT

The construction of an operational upstream facility that provides downstream firms with their essential input takes time. Since the unit price of congestion depends on both upstream and downstream market conditions, the upstream monopolist who chooses the capacity of the essential facility is uncertain about what revenue can be earned from congestion pricing. This paper focuses on uncertainty that only affects demand for the final product. Causes of uncertainty in final product demand include business cycles, population growth and a saturation of durable goods. The optimal two-part tariff on the input purchased by the perfectly competitive downstream firms is investigated when there is uncertainty in final product demand.

4.1 The Model with Uncertainty in Demand for the Final Product

The assumptions made in this section are the same as those made in Section 2 except in relation to demand for the final product. The demand for the final product is now assumed to be a function of both price and the state of the world, $\omega \in \Omega$. In addition, the demand function $D(p, \omega)$ is strictly downward sloping in p for all values of ω. The set of all states of the world, Ω, can be divided into two subsets according to the necessity for rationing: $\Omega_0 = \{\omega | D(p, \omega) \leq K\}$, which includes states in which no rationing occurs, and $\Omega_1 = \{\omega | D(p, \omega) > K\}$, which includes states in which there is rationing. For congestion pricing to be effective, the probability that rationing occurs is assumed to be positive. The variable ω is assumed to be a continuous random variable with a compact range.

The response of the endogenous variables to changes in the access fee and capacity depends on the subset of states to which the world belongs. While the final product price and firm supplies are stochastic variables that depend on ω, the number of firms is not stochastic and n does not depend on ω. In the states in which the capacity constraint is binding, the comparative-static results from Table 1 apply. In the states in which the capacity constraint of the essential facility is not binding, the unit price of congestion is zero and the revenue of the upstream monopolist depends only on the access fee. When there is no rationing, the equilibrium is determined by two conditions: that the downstream firms earn zero profits and that there is no excess demand for the final product. Thus, the equilibrium condition (4) is irrelevant for the comparative statics in states belonging to the subset Ω_0. The results of the comparative-static analysis for the perfect-competition equilibrium for Ω_0 are summarized in Table 3, and the derivation of the partial derivatives in Table 3 is described in Appendix D.

[Table 3 here]

Unlike in the case of states in which the capacity constraint is binding, for Ω_0, an increase in the access fee raises the final product price in equilibrium, and thereby reduces the consumer surplus. This is because the upward shift in the total supply curve of the downstream firms, which is due to this rise in the access fee, raises the final product price along the demand curve when the capacity constraint is not binding. Although an increase in the access fee raises the supply of each individual firm, this additional supply is more than offset by the decrease in total supply associated with the fall in the number of firms due to the increased access fee. Thus, in equilibrium, total demand for the input falls following an increase in the access fee when the capacity constraint is not binding.

4.2 Welfare Analysis under Demand Uncertainty

Based on the comparative-static results in Tables 1 and 3, this section explores the features of the optimal two-part tariff paid by the competitive downstream firms when there is uncertainty about final product demand. In Section 4.2, the expectation of the welfare function in (5) is maximized. The expected value of the welfare function is assumed to be sufficiently regular for the expectations and differentiation operators to be interchangeable (Crew and Kleindorfer, 1976, p. 224). The first-order condition for maximizing the expected value of the welfare function in (5) with respect to the access fee is:

$$E\left(\frac{\partial L}{\partial e}\right) = (1-2\gamma)nP_0 \; + (1-\gamma)eE\left(\frac{\partial n}{\partial e}\right) \leq 0;\; e \geq 0,\; eE\left(\frac{\partial L}{\partial e}\right) = 0\,. \tag{11}$$

where P_0 is the probability that the capacity constraint is not binding, and

$$E\left(\frac{\partial n}{\partial e}\right) = P_0 E\left[\frac{zD'+ny_r}{zy^2}\middle|\Omega_0\right] + (1-P_0)E\left[\frac{ny_r}{zy^2}\middle|\Omega_1\right] < 0\,. \tag{12}$$

Unlike in the case when there is no demand uncertainty about the final product, the necessary condition in (11) includes an additional term, $(1-2\gamma)nP_0$, which represents the welfare effect of the access fee when there is no binding constraint on the capacity of the facility. Except in the case of unconstrained welfare optimization with $\gamma = 0.5$, this term arises unless the capacity constraint is binding in all states; that is, $P_0 = 0$. Thus, solving (11) yields the following proposition about the optimal two-part tariff when there is uncertainty about final product demand.

PROPOSITION 3. *For the maximization of the expected value of constrained welfare or upstream monopoly profits in the perfectly competitive equilibrium when there is uncertainty about final product demand, the access fee must be zero if the capacity constraint is binding in all states, that is, if $P_0 = 0$, and the access fee must be positive if $P_0 > 0$. For the maximization of the expected value of unconstrained welfare, the access fee must be zero for any value of P_0.*

PROOF. If $P_0 = 0$ *or* $\gamma = 0.5$, the first term on the right-hand side of $E(\partial L/\partial e)$ is zero in (11). Then, e must be zero to satisfy the necessary condition, $eE(\partial L/\partial e) = 0$, at the optimum. If $P_0 > 0$ *and* $\gamma < 0.5$, the first term on the right-hand side of $E(\partial L/\partial e)$ is positive. Then, for $E(\partial L/\partial e)$ to be non-positive, e must be positive at the optimum. Q.E.D.

The intuition behind Proposition 3 is straightforward. Uncertainty about final product demand leads to the possibility that the capacity constraint is not binding and no revenue is earned from congestion pricing. To cover this loss in revenue, the access fee must be positive if either the expected value of constrained welfare or expected upstream monopoly profits are being maximized. However, for the maximization of the expected value of unconstrained welfare, there is no need to charge for access to the essential facility to offset the loss in revenue associated with a congestion price of zero. For all objective functions in the case of perfect competition in the downstream sector, congestion pricing alone is sufficient and an access fee is not necessary if the capacity constraint is binding in all states of the world.

The positive access fee associated with maximizing the expected value of constrained welfare or monopoly profits when there is uncertain demand for the final product implies that a two-part tariff is superior to a uniform price of congestion for the input purchased by the competitive downstream firms. The two-part tariff is particularly desirable when congestion pricing applies to usage of the facility that is significantly affected by uncertain demand. This is because uncertainty results in frequent occurrences of a zero congestion price, which discourages the upstream monopolist from expanding capacity. For the upstream monopolist to have an incentive to expand capacity, the revenue from the access fee, which is based on the number of downstream firms and thereby unaffected by uncertainty in market conditions, should be used to cover the substantial investment costs of capacity installation.

Note that uncertainty alone does not necessarily imply the superiority of the two-part tariff over a uniform price for maximizing the expected value of constrained welfare or monopoly profits. A uniform congestion price is superior to a two-part tariff when there is uncertainty about demand for the final product if the capacity constraint is binding in all states of the world. This is because the upstream monopolist can earn revenue from congestion pricing alone if $P_0 = 0$.

With respect to the capacity of the facility, the necessary condition for maximizing the expectation of the objective function in (5) under demand uncertainty is:

$$E\left(\frac{\partial L}{\partial K}\right) = (1 - P_0)\left[E\left(r \mid \Omega_1\right) + \frac{e}{z\bar{y}} - \frac{\Gamma K}{z^2} E\left(\frac{-1}{D'}\middle|\Omega_1\right)\right] - m = 0\,, \tag{13}$$

where $\bar{y}$ indicates the value of y for $\omega \in \Omega_1$. Note that firm supply is identical for any state that belongs to Ω_1 because $y = K/(zn)$ for $\omega \in \Omega_1$. The first term on the right-hand side of (13) represents the expectation of the marginal benefits of capacity installation. For a positive value of K, the expected marginal benefits should be equal to the marginal cost of the facility. For the maximization of the expected value of unconstrained welfare, the condition (13) simplifies to indicate that the expected value of the unit congestion price should be equal to the marginal capacity cost. The effects of uncertainty on vertically related markets are illustrated by a numerical example in Appendix E.

5. CONCLUSION

This paper investigates the optimal structure of a simple two-part tariff. This tariff comprises an access fee and a unit price of congestion for an input supplied by an upstream monopolist from a congestible facility in vertically related markets. Congestion pricing is an efficient form of rationing the demand from downstream firms for access to the essential facility of the upstream monopolist. Assuming congestion pricing is applied to the upstream sector, the optimal access fee must be zero to maximize social welfare or monopoly profits if the downstream market is perfectly competitive. However, if the downstream market engages in Cournot competition, a positive access fee is required to maximize welfare or monopoly profits. A two-part tariff is also superior to a uniform price under constrained welfare maximization or the maximization of monopoly profits if there is uncertainty about demand for the final product and the probability of congestion is less than unity.

Whether a two-part tariff is superior to a uniform price of access to the congestible facility depends on both the market structure of the downstream sector and whether there is uncertainty about final product demand. Using a two-part tariff for congestion pricing in the upstream sector is not optimal if the downstream market is perfectly competitive and there is no uncertainty about final product demand. This result implies that a two-part tariff scheme with a price-cap constraint, which is investigated by Vogelsang (2001), should be applied to industries in which either imperfect competition or demand uncertainty is dominant in the downstream sector.

Examples of network industries in which a two-part tariff on the input with congestion pricing is appropriate include electricity supply and airlines. In electricity supply, a type of congestion pricing known as 'nodal pricing,' which efficiently values electricity demand that depends on time and location, has been applied to a transmission market (Stoft, 2002, Part 5).

Imperfect competition features in a generation market that is vertically related to a transmission market (Green and Newbery, 1992; Borenstein and Bushnell, 1999). Uncertain demand and imperfect competition also feature in transport industries such as airlines, in which congestion pricing is used to mitigate air-traffic delays and in which airlines with access to congested airports have market power (Brueckner, 2002). If congestion pricing is applied to these industries, a fixed fee for access to networks is desirable in terms of constrained welfare maximization.

APPENDIX A: Derivation of the Partial Derivatives in Table 1

To see the response of the final product price to a change in the access fee, firstly total differentiation of (4) yields

$$\frac{\partial p}{\partial e} = 0 \ . \qquad \text{(A1)}$$

Then, totally differentiating (2), and substituting (A1) and the first-order condition for downstream profit maximization yields

$$\frac{\partial r}{\partial e} = -\frac{1}{zy} \ . \qquad \text{(A2)}$$

Equations (A1) and (A2) lead to the response of firm supply to the access fee:

$$\frac{\partial y}{\partial e} = \frac{y_p}{y} = \frac{-y_r}{zy} \ , \qquad \text{(A3)}$$

where $y_p \equiv \partial y/\partial p$ and $y_r \equiv \partial y/\partial r$. Note that $\partial y/\partial r = -z(\partial y/\partial p)$ for perfectly competitive downstream production if the purchased input is in fixed proportion to output, i.e., x=zy. Finally, totally differentiating (3) and substituting (A1) and (A2) yields

$$\frac{\partial X}{\partial e} = 0, \tag{A4}$$

and

$$\frac{\partial n}{\partial e} = -\frac{ny_p}{y^2} = \frac{ny_r}{zy^2}. \tag{A5}$$

As for the response of the final product price to a change in the capacity of the essential facility, total differentiation of (4) yields

$$\frac{\partial p}{\partial K} = \frac{1}{zD'} \quad . \tag{A6}$$

Then, totally differentiating (2) and substituting (A6) yield

$$\frac{\partial r}{\partial K} = \frac{1}{z^2 D'} \quad , \tag{A7}$$

Equations (A6) and (A7) lead to the response of firm supply to a change in capacity:

$$\frac{\partial y}{\partial K} = 0 \ . \tag{A8}$$

Finally, totally differentiating (3), and substituting (A6) and (A7) yields

$$\frac{\partial X}{\partial K} = 1 \quad , \tag{A9}$$

and

$$\frac{\partial n}{\partial K} = \frac{1}{zy} \quad . \tag{A10}$$

APPENDIX B: Derivation of the Partial Derivatives in Table 2

In Cournot equilibrium, the response of equilibrium values of *p* and *X* is equal to that in perfect competition. As for the effects of the access fee, totally differentiating (2) and substituting (A1) yields

$$\frac{\partial r}{\partial e} = \frac{-D'}{zy\left(D' + \frac{y_r}{z}\right)} \quad . \tag{A11}$$

Then, (A1) and (A11) lead to the response of firm supply to the access fee:

$$\frac{\partial y}{\partial e} = \frac{-y_r D'}{zy\left(D' + \frac{y_r}{z}\right)} \quad . \tag{A12}$$

Finally, totally differentiating (3), and substituting (A1) and (A11) yields

$$\frac{\partial n}{\partial e} = \frac{n y_r D'}{zy^2\left(D' + \frac{y_r}{z}\right)} \quad . \tag{A13}$$

Turning to the effects of the capacity of the facility, totally differentiating (2) and substituting (A6) yields

$$\frac{\partial r}{\partial K} = \frac{D' - y_p}{zD'(zD' + y_r)} \quad . \tag{A14}$$

Equations (A6) and (A14) lead to the response of Cournot firm supply to a change in capacity:

$$\frac{\partial y}{\partial K} = \frac{zy_p + y_r}{z(zD' + y_r)} \quad . \tag{A15}$$

Finally, totally differentiating (3), and substituting (A6) and (A14) yields

$$\frac{\partial n}{\partial K} = \frac{zD' + y_r - n(zy_p + y_r)}{zy(zD' + y_r)} \quad . \tag{A16}$$

If *D*' is independent of the final product price as in the case of a linear demand curve, $zy_p = -y_r$, the response of endogenous variables to a change in parameter *K* in Cournot equilibrium becomes the same as that in perfect competition equilibrium.

APPENDIX C: Derivation of the Optimal Two-Part Tariff of the Input in Cournot Equilibrium by Applying the Model of Ordover and Panzar (1982)

The model is as in the identical firm case with a fixed proportion between *x* and *y* ($x=zy$, $z>0$) investigated by Ordover and Panzar (1982), who assume that *r* and *e* are parameters and p, n, and x are endogenous variables, except that the downstream market is described by Cournot competition. Ordover and Panzar also assume that capacity never constrains the demand for the input, and parameter K and congestion pricing are irrelevant to the analysis. Total cost of the upstream monopolist is assumed to only depend on total demand for the input. The objective function is assumed to be

$$L = \gamma\int_{p} D(w)dw + (1-\gamma)[(r-m_1)X + en - m_0] \tag{A17}$$

where m_1 indicates marginal cost for the upstream monopolist.

In equilibrium, two conditions in (2) and (3) hold. Totally differentiating (2) yields

$$\frac{\partial p}{\partial e} = \frac{D'}{y(D'-y_p)} \quad , \tag{A18}$$

and

$$\frac{\partial p}{\partial r} = \frac{zD'+y_r}{D'-y_p} \quad . \tag{A19}$$

Totally differentiating (3), and substituting (A18) and (A19) yields

$$\frac{\partial X}{\partial e} = \frac{zD'^2}{y(D'-y_p)} \quad , \tag{A20}$$

$$\frac{\partial X}{\partial r} = \frac{zD'(zD'+y_r)}{D'-y_p} \quad , \tag{A21}$$

$$\frac{\partial n}{\partial e}=\frac{D'(D'-ny_p)}{y^2(D'-y_p)} \quad , \tag{A22}$$

and

$$\frac{\partial n}{\partial r}=\frac{(zD'+y_r)(D'-ny_p)}{y(D'-y_p)}-\frac{ny_r}{y} \quad . \tag{A23}$$

It should be noticed that a lemma that $\partial X/\partial e=\partial n/\partial r$ in Ordover and Panzar, which holds in perfect competitive equilibrium, does not hold in case of Cournot equilibrium of the downstream sector.

Using (3), (A18) and (A19), the first-order conditions for maximizing the objective function in (A17) simplify to

$$\frac{\partial L}{\partial e}=-\gamma D\frac{\partial p}{\partial e}+(1-\gamma)n+(1-\gamma)(r-m_1)\frac{\partial X}{\partial e}+(1-\gamma)e\frac{\partial n}{\partial e} \tag{A24}$$

$$\frac{\partial L}{\partial r}=-\gamma D\frac{\partial p}{\partial r}+(1-\gamma)nx+(1-\gamma)(r-m_1)\frac{\partial X}{\partial r}+(1-\gamma)e\frac{\partial n}{\partial r} \quad . \tag{A25}$$

Inserting four equations (A20)-(A23) into (A24) and (A25), the following relationships are obtained:

$$\frac{\partial L}{\partial e}=\frac{-\gamma nD'}{D'-y_p}+(1-\gamma)\left[\frac{(r-m_1)zD'^2}{y(D'-y_p)}+n+\frac{eD'(D'-ny_p)}{y^2(D'-y_p)}\right] \tag{A26}$$

$$\frac{\partial L}{\partial r} = \frac{-\gamma D(zD'+y_r)}{D'-y_p}$$

$$+(1-\gamma)\left[\frac{(r-m_1)zD'(zD'+y_r)}{D'-y_p} + X + \left(\frac{e}{y}\right)\frac{(zD'+y_r)(D'-ny_p)-ny_r(D'-y_p)}{D'-y_p}\right]$$

(A27)

Substituting $\partial L/\partial r$ =0 into the second term on the right-hand side in (A26) yields

$$\frac{\partial L}{\partial e} = n(1-\gamma)\left(\frac{y_r}{zD'+y_r}\right)\left(1+\frac{eD'}{y^2}\right) \leq 0 \quad . \tag{A28}$$

Thus, from (A28) and $e(\partial L/\partial e)$=0, e must be positive and the optimal access fee in Cournot equilibrium is given by $e=y^2/(-D')$. This optimal solution for the access fee is equal to that obtained from (8) in Section 3.2.

APPENDIX D: Derivation of the Partial Derivatives in Table 3

Since the unit congestion price must be zero in the states that the capacity constraint is not binding, firm supply is the function of the final product price and a change in the capacity of the facility does not affect endogenous variables in these states. Total differentiation of (2) yields

$$\frac{\partial p}{\partial e} = \frac{1}{y} \quad , \tag{A29}$$

and

$$\frac{\partial y}{\partial e} = \frac{-y_r}{zy} \quad . \tag{A30}$$

Totally differentiating (3) and substituting (A29) and (A30) yields

$$\frac{\partial X}{\partial e} = \frac{zD'}{y} \ , \tag{A31}$$

and

$$\frac{\partial n}{\partial e} = \frac{zD'+ny_r}{zy^2} \ . \tag{A32}$$

APPENDIX E: A Numerical Example of the Effects of Uncertainty on Vertically Related Markets with Congestion Pricing

Suppose that the demand function $D(p, \omega)$ is linear and takes the following form:

$$D(p, \omega) = 20 - p + \omega \ . \tag{A33}$$

A stochastic variable ω is supposed to be uniform and distribute on [0, 20]. Thus, the probability that ω occurs is given by 0.05. Each downstream firm is supposed to require one unit of the input in question to produce one unit of output so that z=1. The cost function of each downstream firm is linear and takes the following form:

$$C_d(y) = 5 + 10y^2 \ . \tag{A34}$$

Then, the marginal cost is given by 20y and the firm supply function becomes

$$y(p, r) = (p - r)/20 \ . \tag{A35}$$

Finally, the total cost of the upstream facility is supposed to be

$$C_m = m_0 + 1.25K \tag{A36}$$

Based on these functional forms in (A33)-(A36), the optimal values for expected unconstrained welfare maximization and upstream profit maximization are respectively obtained by simultaneously solving the equilibrium conditions and first order conditions. For both cases, an equilibrium condition of $zD=zny=X=K$ is imposed on the computation of the optimal solutions. A Gauss-Newton method is used to solve a simultaneous-equation system that consists of three reduced-form equations and three variables (e, n, and K).

Table 4 compares equilibrium values of key variables between expected unconstrained welfare maximization and upstream profit maximization. Compared with the case of expected unconstrained welfare maximization where e=0, the profit maximizing upstream monopolist raises the access fee to 2.4, thereby reducing the number of downstream firms approximately by 57%. The profit-maximizing monopolist lowers the upstream capacity approximately by 52% to increase revenue from congestion pricing. As a result, the monopoly optimal price of congestion becomes four times as large as the welfare optimal price of congestion. The probability of congestion in the profit maximization case becomes double of that in the welfare maximization case.

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Table 1. Effects of the access fee and capacity of the essential facility on key endogenous variables in perfectly competitive equilibrium (directions of changes are indicated by signs in parentheses)

$\partial p/\partial e$	$\partial r/\partial e$	$\partial y/\partial e$	$\partial n/\partial e$	$\partial X/\partial e$
0	$-1/(zy)$ (−)	$-y_r/(zy)$ (+)	$ny_r/(zy^2)$ (−)	0
$\partial p/\partial K$	$\partial r/\partial K$	$\partial y/\partial K$	$\partial n/\partial K$	$\partial X/\partial K$
$1/(zD')$ (−)	$1/(z^2D')$ (−)	0	$1/(zy)$ (+)	1 (+)

Table 2. Effects of the access fee and capacity of the essential facility on key endogenous variables in Cournot equilibrium (directions of changes are indicated by signs in parentheses)

$\partial p/\partial e$	$\partial r/\partial e$	$\partial y/\partial e$	$\partial n/\partial e$	$\partial X/\partial e$
0	$\dfrac{-D'}{zy\left(D'+\dfrac{y_r}{z}\right)}$ (−)	$\dfrac{-y_r D'}{zy\left(D'+\dfrac{y_r}{z}\right)}$ (+)	$\dfrac{ny_r D'}{zy^2\left(D'+\dfrac{y_r}{z}\right)}$ (−)	0
$\partial p/\partial K$	$\partial r/\partial K$	$\partial y/\partial K$	$\partial n/\partial K$	$\partial X/\partial K$
$\dfrac{1}{zD'}$ (−)	$\dfrac{D'-y_p}{z^2 D'\left(D'+\dfrac{y_r}{z}\right)}$ (−)	$\dfrac{zy_p+y_r}{z(zD'+y_r)}$ (+−)	$\dfrac{zD'+y_r-n(zy_p+y_r)}{zy(zD'+y_r)}$ (+−)	1 (+)

Table 3. Effects of the access fee on key endogenous variables in perfectly competitive equilibrium, when the capacity constraint is not binding (directions of changes are indicated by signs in parentheses)

$\partial p/\partial e$	$\partial y/\partial e$	$\partial n/\partial e$	$\partial X/\partial e$
$1/y$ (+)	$-y_r/(zy)$ (+)	$(zD' + n\, y_r)/(zy^2)$ (−)	zD'/y (−)

Table 4. Computation results of key variables in a numerical example of Appendix E

	E(y)	E(p)	E(r)	n	K	$1-P_0$	e
Welfare maximization	0.70	15.2	1.25	21.1	16.9	0.35	0
Upstream Profit maximization	0.86	22.2	5.06	9.1	8.1	0.71	2.4