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"PRICING OF NETWORK SYSTEMS AND CONSUMPTION EXTERNALITIES"

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1. INTRODUCTION

Usually, there are important externalities in telecommunications networks. In fact, an externality is created every time a phone is used because the recipient of the call obtains a benefit for which he does not pay. Similarly, a new subscriber confers a benefit on existing subscribers because they are now able to call the new subscriber. The existence of these externalities should be taken for allocative purposes, namely, "optimal pricing" decisions.

This particular subject has been studied often by the economists, especially with respect to telephonic networks. However, in most cases, the analysis and proposed solutions apply to other types of telecommunications networks. That is the case of the work developed by Littlechild (1972, 1975), Gravelle (1972), Squire (1973), Artle and Averous (1975), and, more recently, Oren and Smith (1981).

The purpose of this paper is to determine the optimal price of access to a telecommunications network--the flat part of a two-part tariff system--using a simpler model than the ones presented in the existing literature, but that will yield qualitatively identical conclusions. In our model, we shall explicitly consider the existence of a consumption externality, since the entry of new subscribers to the system increases the utility of each and every already installed subscriber: we shall take explicitly into account that these individuals benefit from being able to communicate through the system with a larger number of individuals (other subscribers).

Section 2 summarizes the questions resulting from the existence of external effects in telecommunications networks and presents the main results of the existing literature. Section 3 presents the model and its main results. Section 4 comments on the results of the model, discusses its main weaknesses and suggests some directions for future research.

2. THE PROBLEM OF EXTERNALITIES IN TELECOMMUNICATIONS; SURVEY OF THE LITERATURE

The issue of externalities in telecommunications networks springs from the widely held notion that each person joining the telecommunications network thereby confers benefits on other subscribers. Indeed, it has been suggested that each person originating a call thereby confers a benefit on the person receiving the call.

Analytic models of consumption externalities in telecommunications systems were developed by Littlechild (1972, 1975), Gravelle (1972), Squire (1973), Artle and Averous (1975), and Oren and Smith (1981).

Without going into the details of these models, the main assumptions and results can easily be stated. Suppose that a subscriber's demand for calls depends on his income, the price of a call and the total number of subscribers. Suppose also that the company that supplies the service wishes to maximize the total surplus of the system (i.e., consumers' plus producers' surplus). In the absence of any financial constraint and assuming that the price of each call is set equal to its marginal cost, the optimal policy requires that the number of subscribers be increased to the point where the marginal cost of accommodating a subscriber equals the marginal value which he/she receives, plus the increase in consumer surplus which he/she generates for all other subscribers. To attain this optimal number of subscribers, the subscription rate should be set below marginal customer cost by an amount equal to the external benefit received by other subscribers. This external benefit essentially comprises the consumer surplus enjoyed by existing subscribers on calls that can now be made to the new subscriber. It may be shown (Littlechild, 1975) that this is equal to the average consumer surplus per subscriber, multiplied by the elasticity of demand for calls with respect to number of subscribers in the system.

An additional dimension to the externalities question has been provided by Squire (1973). He remarks that, of all public utilities, telecommunications "affords one of the best instances of external economies. In fact, it would appear that an externality is created every time a phone is used because the recipient of the call obtains a benefit for which he does not pay." The efficient allocation of resources thus requires that a call be made if and only if the value of that call to the sender plus the value to the receiver exceeds its marginal cost. If one assumes, as a first approximation, that the expected benefit from an incoming call is the same for all subscribers, optimal policy is to set the price of the call below its marginal cost by the (constant) amount of this benefit.

If this proposal to subsidize calls to correct for external benefits is to be taken seriously, several conditions must be satisfied. First, the external benefits obtained by the recipients of calls must be substantial. Second, there must be a substantial number of calls which are not presently made but which "ought" to be made if external benefits are taken into account. The fact that recipients of calls presently made derive great benefits from them is irrelevant. Third, there must be no alternative method available and worth using by which the potential recipient can ensure that the calls in question are made. Fourth, subsidizing calls should not cause other distortions which more than offset the benefits of the subsidy.

These comments and qualifications which refer to the evaluation of externalities associated with calls, can also apply to externalities generated by new subscribers. Certainly a telecommunications system consisting of a single subscriber is worthless, and consequently any addition to the network, by increasing the set of people it is possible to call or receive calls from, makes the network more valuable. Again, the question to ask is whether there are many people who are not connected to the system but who, nevertheless, ought to be in the network because enough existing subscribers would, together, receive benefits in excess of the marginal cost of adding them. If there are people who ought to be in the network but are not, further questions arise: who are these potential subscribers, and how can they be brought into the network without also bringing in the "wrong" people (i.e., those whose values to others is less than marginal cost)? These externalities associated with the number of subscribers may not be easily internalized: negotiation among parties may not be easy because there are likely to be many potential beneficiaries of a potential subscriber, who may not all be known to each other; even if they were, it would be difficult for them to reach an agreement about sharing the rental fee. Thus, "transactions costs" may prevent subscribers externalities from being internalized.

Where externalities are significant, there should be a way of reducing the rental to these potential subscribers without also reducing it to the ones already installed. It would seem possible, selectively, to reduce rentals or installation charges in specified geographical areas, but there is no strong reason to believe that this would isolate the desired subscribers. The alternative to selective reductions is an overall reduction in rental, or at least a reduction for certain broad classes of customers (e.g., business firms). Unless a government subsidy is to be provided, this will need to be financed either by increasing the rental to other groups of subscribers, or by increasing call charges. Both of these devices will cause their own misallocation of resources. These disadvantages must be balanced against the advantages of extending the network.

As we have already mentioned, the above presented considerations inspired the work of Littlechild, Gravelle, and Squire. Other authors followed a somewhat different approach to these externality problems. Artle and Averous (1975) wrote an article where they considered a communication network as a "public good," showing that the increase in the value of the service resulting from new subscribers can sustain the continual growth of a network in a stationary population with stationary income. Their analysis is based on the assumption that a "uniform calling pattern" (i.e., the incremental utility of the service to an individual) depends on the number of subscribers but not on their identity.

More recently, the literature on efficient pricing of telecommunications has become more sophisticated. Oren and Smith (1981) developed an economic model that determines both the required critical mass for startup and the ultimate expansion level of such a system in the presence of externalities. They used a model in which users maximize benefits minus cost and a monopoly supplier maximizes profit in order to evaluate the effects of different pricing structures for the system. In their pricing analysis, they consider a "three-part tariff," composed of a fixed charge, an initial free volume, and a marginal charge per unit for additional volume. Using demand functions in which price and externality effects are multiplicatively separable, they were able to illustrate as their three-part price plan can facilitate the formation of critical mass levels by reducing the fraction of subscribers required, when one assumes optimizing behavior by both the users and the supplier of the service. Furthermore, they were able to show that, for monopoly profit maximization, the market effects of the optimal three-part tariff can be duplicated by an appropriate two-part tariff.

3. OPTIMAL NETWORK PRICING

3.1 THE PROBLEM; ASSUMPTIONS

In this section we want to determine the optimal access fee to a telecommunications network--the flat part of a two-part tariff system.

We shall explicitly consider the existence of an externality, since the entry of new subscribers to the system increases the utility of each and every already installed subscriber. We take explicitly into account that these individuals benefit from being able to communicate through the system with a larger number of individuals (other subscribers).

To address this problem, we will use a simple model with some simplifying assumptions:

H1: Receiving calls has no effect upon subscribers utility (i.e., we ignore that the receiver of a call has a benefit that does not pay).

H2: The Income effect is neglected because we consider that the Network use expenditures are but a small fraction of each subscriber's budget.

H3: We do not consider possible congestion effects in the system.

H4: All new subscribers are "equally welcomed" (i.e., we consider that the externality is the same regardless of whoever is the new subscriber).

H5: The firm that supplies the service does not face any binding financial constraint: it will be able to receive from the government whatever funds it wants.

3.2 THE MODEL

Let

Pa: annual access fee to the network[1]

Ca: annual cost of renting and maintaining a connectivity; assumed constant

Pc: price of each call[2]

Cc: marginal cost per call; constant

CA: average number of calls per subscriber

A: number of subscribers of the system

NA: number of new subscribers

k: increase in utility for each subscriber resulting from the entry of a new subscriber in the system

b: minus the slope of the demand for network connectivity schedule[3]

The demand for calls per subscriber is given by:

$$CA = \eta \ Pc^{\alpha} A^{\beta} \qquad \text{(I)}$$

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[1]The time unit considered does not restrict the generality of the analysis.

[2]"Call" means unit of time of network use.

[3]Which is approximately Linear, by assumption.

Initially, we assume that the access fee to the network is set equal to the marginal cost of installation of the connectivity (Pa = Ca), being Ao the number of initial subscribers. This would be the optimal policy if there were no externality. However, this is not the case, because we assume that the entry of new subscribers yields an increase in the utility of each subscriber, given that the number of subscribers to whom he/she may call increases.

If the access fee to the network is set below Ca, new subscribers will enter into the system. Given the externality effect already mentioned, the utility of each subscriber increases by k for each new individual that joins the system. Therefore, the value of k represents the increase in each subscriber's surplus, relative to the "consumption" of calls.

Now, consider Fig. 1. Admitting that NA new subscribers join the system, the demand for calls of the representative subscriber increases from D_o^1 to D_1^1, and hence his/her surplus increases by k · NA (k for each new subscriber). Therefore, the willingness to pay for the rent of the connectivity also increases

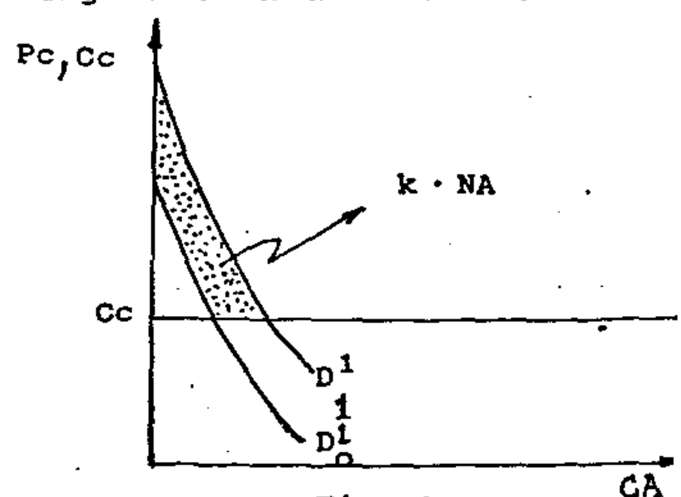

Fig. 1

by k · NA for each subscriber and then the schedule D_o in Fig. 2 shifts to D_1. Given that in the final situation there are A_1

subscribers ($A_1 = A_o + NA$), the total increase in the surplus is given by the area between D_o and D_1, and between O and A_1.

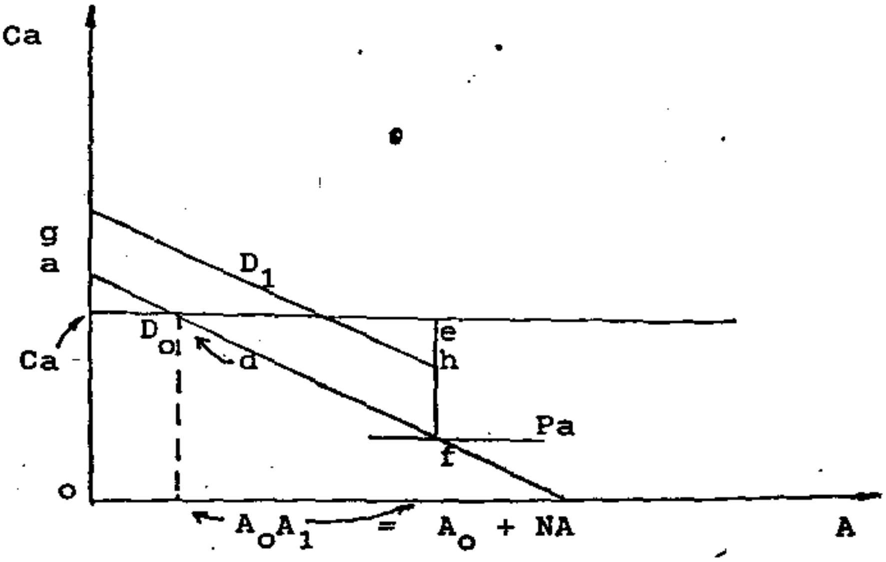

Fig. 2

On the other hand, the departure from Marginal Cost pricing implies inefficiency costs given by the area of the triangle [d e f] in Fig. 2.

Thus, the determination of the optimal price scheme for the network services (optimal annual access fee to the network) consists in maximizing the difference between these two areas. The area of the parallelogram [a g h f] is given by A_1 k NA, while the area of triangle [d e f] corresponds to $\frac{1}{2b}$ $(Ca-Pa)^2$.[4]

[4] Area [d e f] $= \frac{1}{2} \cdot (Ca-Pa) \cdot NA$ but $NA = \frac{(Ca-Pa)}{b}$ since the demand curve is a straight line with slope b. Thus, area [d e f] $= \frac{1}{2}$ $(Ca-Pa) \frac{(Ca-Pa)}{b} = \frac{1}{2b}$ $(Ca-Pa)^2$.

Hence, we want to determine Pa that maximizes

$$W = k \cdot NA \quad (A_o + NA) - \frac{1}{2b} (Ca-Pa)^2 \qquad (II)$$

Since NA = $\frac{1}{b}$ (Ca-Pa), (II) can be written as:

$$W = \frac{k}{b} (Ca-Pa) \left(A_o + \frac{(Ca-Pa)}{b}\right) - \frac{1}{2b} (Ca-Pa)^2$$

The First Order condition is:

$$\frac{dW}{dPa} = - \frac{1}{b} k A_o + \frac{2k}{b^2} (Ca-Pa) (-1) + \frac{1}{b} (Ca-Pa) = 0$$

or

$$- \frac{1}{b} k A_o - 2 k \frac{1}{b} NA + \frac{1}{b} (Ca-Pa) = 0 \qquad (III)$$

Solving (III) for Pa we can deviate the optimal policy:

$$P_a = C_a - k (A_o + 2 NA) \qquad (IV)$$

Rearranging (IV) we have

$$b Pa = b Ca - b k A_o - 2 k Ca + 2 k Pa$$

or $\quad Pa (b - 2k) = (b - 2k) Ca - b k A_o$

which leads to

$$Pa = Ca - \frac{k A_o}{1-2\frac{k}{b}} \qquad (V)$$

If the Second Order conditions are verified, then k < b/2.[5] Thus, 1 - 2k/b is positive and Pa < Ca.

We can see in (V) that the crucial variable in the determination of the externality effect is k. Therefore, the next step is to evaluate k.

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[5]The Second Order condition are:

$$\frac{d^2W}{dP_a^2} = 2 k \frac{1}{b^2} - \frac{1}{b} < o \text{ or } 2 k - b < o$$

Given (I), the consumer surplus for each subscriber is given by[6]

$$U_i = \int_0^{\eta Cc^{\alpha} A^{\beta}} [\eta^{-1/\alpha} CA^{1/\alpha} A^{-\beta/\alpha} - Cc] dCA \quad \text{(VI)}$$

Since we defined k as the increase in utility for each subscriber resulting from the entry of a new subscriber in the system, it is[7]

$$k = \frac{\Delta U_i}{\Delta A} \cong \frac{\partial U_i}{\partial A} = \beta \eta A^{\beta-1} Ca^{\alpha+1} (\frac{\alpha}{\alpha+1} - 1) = \beta \frac{U_i}{A} \quad \text{(VII)}$$

There is a positive externality if β (and consequently k) is positive.[8] If $\beta = o$, U_i does not depend upon A (i.e., there is no externality), and $k = o$.

We conclude that, given the assumption of this model, the optimal policy requires the number of subscribers to be increased

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[6] Solving (I) for Pc we obtain $Pc = \eta^{-1/\alpha} CA^{1/\alpha} A^{-\beta/\alpha}$.

[7]

$$U_i = \int_0^{\eta Cc^{\alpha} A^{\beta}} [\eta^{-1/\alpha} CA^{1/\alpha} A^{-\beta/\alpha} - Cc] \, dCA =$$

$$= [\frac{\alpha}{\alpha+1} \eta^{-1/\alpha} CA^{\frac{\alpha+1}{\alpha}} A^{-\beta/\alpha} - Cc]_o^{\eta Cc^{\alpha} A^{\beta}} =$$

$$= \frac{\alpha}{\alpha+1} \eta^{-1/\alpha} (\eta Cc^{\alpha} A^{\beta})^{\frac{\alpha+1}{\alpha}} A^{-\beta/\alpha} - CcCA \; \frac{\alpha}{\alpha+1} \eta^{\frac{\alpha-1}{\alpha}} Cc^{\alpha+1} A^{\beta} -$$

$$- \eta C_c^{\alpha+1} A^{\beta}$$

[8] Note that U_i must be positive; otherwise, the subscribers would leave.

until the point where the marginal cost of accommodating one more subscriber is equal to the increase in consumer surplus for all subscribers that is then generated.

Equation (V) shows that in order to obtain this ideal number of subscribers, the price should be below Ca. This gap between Pa and Ca depends upon the importance of the external effect (for greater k the gap is larger) and the number of subscribers already installed which benefit from the above-mentioned positive external effect.

4. CONCLUSION AND EXTENSIONS

We were able to use a simpler model to obtain the same type of results as the existing literature. Indeed, our result is, to some extent, similar to the one produced by Squire (1973). Both models indicate a below-marginal cost pricing policy; the difference is that while Squire suggests that the price per call should be set below its marginal cost by the (constant) amount of the benefit for subscribers from an incoming call, our model indicates that in order to obtain the ideal number of subscribers, the annual access tariff to the network system should be below marginal cost. In both models, the gap between price and marginal cost depends upon the importance of the external effect (the size of the gap should increase with the importance of the externality). The point we are trying to make is that, even though in one case we are dealing with calls and in the other we deal with access to the system and number of subscribers, the results are (as expected) qualitatively similar.

Our model was also useful to address the problem--previously treated by Littlechild (1975) and Squire (1973)--of determining the optimal number of subscribers in a telecommunications network: the number of subscribers should be increased until the point where the increase in cost of having one more subscriber in the system is equal to the generated increase in consumer surplus for all subscribers. Note that this result is slightly different from what we presented in section 2, a result of the different assumptions that we used.[9]

The model presented is very limited, particularly because it does not take into account the existence of dynamic effects, namely, on the demand side. In the model it would be interesting to incorporate that subscriber's elasticity of demand is not constant over time--it is lower for a subscriber already in the system than for a potential entrant.

The limited assumptions that we used can be successively dropped, allowing for future developments of the model used. Several characteristics of network systems that were left out

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[9]Specifically, we only consider the externality that results from the entry of new subscribers to the system. Thus the optimal annual access fee to the system is the one that maximizes the benefit conferred upon all existing telephone owners when new customers join the system. Squire (1973) and Littlechild (1975) consider first-best optimal pricing strategies for two-part tariffs when both access and usage externalities are present.

Our model was simpler also because we ruled out the existence of an income effect. Its inclusion was proven to be irrelevant in terms of the qualitative conclusions of the model.

could be introduced into the analysis. Many telecommunications (namely, telephone) systems are congested in the sense that the probability of achieving a connection immediately is low. Recommending prices below marginal cost may, therefore, exacerbate an already inferior system. This problem can be taken care of if we determine optimal prices which take explicit account of congestion as represented by a functional relationship between the number of calls and the delay per call. There is, however, a more fundamental problem which must be considered. The analysis set out to establish economically efficient pricing rules in a situation where externalities are prevalent. This meant, in general, that the enterprise ran at a commercial loss. Such a situation may be acceptable in developed countries but in the underdeveloped countries subsidies from general taxation are not easy to secure. It might be interesting, therefore, to reexamine the pricing rules, given the constraint that profits are non-negative. Alternatively, we could introduce directly into the analysis the premium that the government places on its own revenue. This latter method would secure an economically efficient result and, as mentioned by Littlechild (1975), could mean, for instance, that we "use telecommunications as a source of general revenue."

Two other limitations of the model can be eliminated if we explicitly acknowledge that receiving calls has an effect upon subscribers' utility and that the externality is not independent of who are the new subscribers.

It will be interesting to extend our simple model taking into account the above-presented considerations, to see whether we will be led to results qualitatively different from the one we obtained in the previous section. Moreover, a comprehensive treatment of all the problems involved in the optimal pricing of telecommunications in the presence of externalities would also be a valid contribution for the existing literature in the area.

REFERENCES

Artle, R., and Averous, C. The Telephone System as a Public Good: Static and Dynamic Aspects. Bell Journal of Economics, 4(1), Spring 1975, pp. 89-100.

Gravelle, H. S. E. A Note on Telephone Rentals: Comments. Applied Economics, 2(2), 1972, pp. 235-238.

Littlechild, S. C. A Note on Telephone Rentals. Applied Economics, 2(2), 1972, pp. 73-74.

Littlechild, S. C. Two-part Tariffs and Consumption Externalities. Bell Journal, 6(2), Autumn, 1975.

Oren, S., and Smith, S. Critical Mass and Tariff Structure in Electronic Telecommunications Market. Bell Journal, 12(2), Autumn 1981.

Squire, L. Some Aspects of Optimal Pricing for Telecommunications. Bell Journal, 4(2), Autumn 1973.