Economic Methodologies for Pricing of Broadband Services

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Abstract

This paper presents a brief overview of commonly accepted pricing rules and procedures that can be employed in pricing telecommunications services generally, and that may be particularly relevant in pricing of broadband VDT services. Two aspects of VDT services are emphasized. First, while the technology permits a wide array of new services to be delivered on a common distribution network, these services will differ profoundly from one another in their demand and cost characteristics. For example, video services require substantially larger bandwidth than traditional voice and data services, and they also have entirely different demand characteristics. Markets for new video services may not develop if traditional pricing methodologies are followed, or if restrictive regulatory policies are imposed. On the other hand, these services will be offered, at least initially, on a tariffed basis in which regulatory oversight must be accepted. Therefore the paper surveys some of the commonly accepted principles upon which prices in regulated and partially regulated markets are determined.

The second characteristic of VDT pricing emphasized in this paper is the issue of customer arbitrage. High bandwidth service offerings can potentially be resold as voice and low speed data. Furthermore it may be technically difficult, if not impossible, to detect or prevent the repackaging and resale of high capacity services, just as resale of WATS and private line services as MTS has occurred in the past. In fact, in some cases regulatory authorities have encouraged such resale as a pro-competitive policy. While no simple solution is evident, we discuss some of the pricing strategies that might be used to mitigate the arbitrage problem to some extent. By appropriately differentiating new services on the basis of priority of service, cell loss, delay and security, it may be possible to induce customers to self-select among service offerings in a manner that will allow service providers to maximize the revenue potential from all services. It is also suggested that in the long run, customer arbitrage might best be prevented by seeking new revenue sources such as from the bundling of advertising with certain services.

Economic Methodologies for Pricing of Broadband Services

1. Introduction

In this paper, we consider some of the long term issues associated with pricing of broadband telecommunications services, including video dial tone (VDT) services. Future broadband digital networks (BISDN) will be based on a technological platform that will support voice, data, image and video services. Policy makers and regulators have not yet reached a consensus on how these services will be deployed and priced in a competitive market. There are opportunities for Bellcore to provide inputs into these decisions. Moreover, Bellcore's owners have some flexibility in pursuing various business strategies regarding broadband deployment. We therefore seek to provide economic inputs which may be useful in developing appropriate technological, regulatory and marketing strategies.

Consider first a very simple arithmetical exercise conducted by Robert Pepper of the FCC[1]. A naive cost-based price structure would price every ATM cell alike, regardless of the traffic it represented. If each ATM cell is priced identically, and this price is chosen so that a local call costs a penny per minute, he argued that a two hour video movie (at 45 Mbps) would cost about $843.75. With compression and transmission at T1 speeds, the price for a movie would fall to about $30. This is unacceptably high when compared to substitutes such as movie rentals.

Pepper's solution was to suggest that every house should be given sufficient bandwidth for a voice plus TV channel, and be charged a flat rate equal to today's average expenditure on local calls and basic cable service (about $40). This pricing approach opens up some very lucrative arbitrage opportunities. An apartment building could install a PBX and order a few lines, each with the capacity for about 700 voice circuits (45Mb/64Kb). These voice services could be resold to tenants for considerably less say $10 per month per tenant, and generate huge profits for the reseller. Tenants could purchase video services from other vendors such as cable companies.

Arbitrage opportunities such as the one described above arise because services with very different bandwidth requirements are priced similarly. The history of telecommunications shows clearly that when arbitrage opportunities are made available, the market responds with alacrity. WATS resale, aggregation and resale of multi-location calling plans (MLCPs), and International Discount Telecommunications' "callback" service all arose from arbitrage incentives built into existing pricing structures.

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[1] Pepper, R. *Through the Looking Glass: Integrated Broadband Networks, Regulatory Policies and Institutional Change*, FCC Office of Plans and Policy Working Paper No. 24, 1988, p. 46.

There is no single "economically correct" model which can be used to price broadband services, or to resolve the above issues. In the following sections of this paper we will survey a significant body of relevant work that can be applied to the pricing of video dial tone services. We will consider the application of pricing methodologies in both partially regulated and in fully competitive markets, and will focus particular attention to the problem of customer resale and arbitrage. Some of the specific pricing methodologies will be presented in mathematical terms, since implementation of the relevant ideas will ultimately require a precise formulation. We have attempted, however, to convey the relevant ideas in non-technical language at the beginning of every section. In a brief concluding section we will indicate how the results in all of the sections can be utilized by BCCs in setting actual prices.

2. Demand Based Pricing

The question of pricing of broadband telecommunications services can be addressed in terms of a general framework of pricing rules for a multiple product firm. We first consider the standard economic approach to pricing in multiple product firms assuming profit maximization as an objective.[2] If a firm produces a single product, the determination of a profit maximizing price requires a knowledge of the demand function facing the firm and its cost of producing any conceivable output. The demand function is simply a schedule of output quantities that the firm expects to sell at any given price, and the cost function describes the total cost associated with each output. At a sufficiently high price demand will be negligible, so that total profits will be small (even though the profit per unit sold is large). As price is lowered, more units can be sold, and as long as the increased revenue exceeds the increased cost, profits to the firm will increase. The optimum profit maximizing output is the one in which the incremental (or marginal) revenue from an increase in sales exactly matches the marginal cost of an increase in output.

When a firm produces more than one output similar principles apply, but the firm must now take into account the interactions on both the demand and cost side of increases in any one of its outputs. To describe the profit maximizing rule in this case it is necessary to introduce some mathematical notation. Suppose that $q = (q_1 ,..., q_n)$ represents a vector of possible outputs for the firm and let $C(q)$ represent the total cost of producing the output vector q. If demands for each of the firm's products are independent, it is possible to write the inverse demand function $p_i = P_i(q_i)$ which expresses the amount that customers are willing to pay for the last unit produced when output is q_i.[3] If the firm is unregulated, profit maximization is achieved by equating

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[2] An elementary exposition of the theory of multiproduct monopoly pricing is contained in Stigler, G. *The Theory of Price*, third edition, London: Macmillan Company, 1966, p.211. A more rigorous treatment may be found in Tirole, J. *The Theory of Industrial Organization*, Cambridge, MA: MIT Press, 1989, p.69.

marginal revenue with marginal cost in each market. The expression for marginal revenue is commonly expressed in terms of the elasticity of demand $\eta_i = \frac{p_i}{q_i}\frac{dq_i}{dp_i}$, so that from the equality of marginal revenue and marginal cost one can derive the expression $p_i\left(1+\frac{1}{\eta_i}\right)=\frac{dC}{dq_i}$[4]. Since marginal costs are typically greater than zero, it follows that a monopolist will always choose a price at which marginal revenue is positive, which means that demands will always be elastic (i.e. $\eta < -1$). If the demands are interrelated, the appropriate marginal revenue must be adjusted to reflect the effect of a change in the price of one product on the revenues that may be obtained in all other markets.

The formula for the optimal pricing rule for a multiple product monopolist is a special case of the so-called "Ramsey pricing rule" which is appropriate whether or not the firm is regulated. Where a monopoly firm seeks to maximize its profits without any constraints on their level, a regulated firm may have as its objective the maximization of social surplus[5] subject to a budget constraint that is imposed by the regulatory process. The Ramsey pricing rule in the case of independent demands is given by the formula

$$\frac{p_i - \frac{dC}{dq_i}}{p_i} = -\frac{k}{\eta_i}.$$

The number k is chosen to satisfy the budget constraint, where $k = 1$ corresponds to unconstrained profit maximization, $0 < k < 1$ corresponds to budget constrained pricing when there are increasing returns to scale, so that prices in excess of marginal cost are required to recover total costs, and $k < 0$ corresponds to budget constrained pricing under decreasing returns to scale.[6]

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[3] When demand are not independent the inverse demand function depends on all other quantities produced by the firm. We note that our analysis also ignores income effects, which is reasonable in an analysis of telecommunications demand functions.

[4] Since total revenue in market i is given by $P_i(q_i)\, q_i$, profit maximization requires choosing output q_i such that

$$\frac{d}{dq_i}\left[P_i(q_i)q_i\right] = \frac{d}{dq_i}\left[C(q_1,\dots,q_n)\right]$$

[5] Social surplus is defined as profits plus aggregate consumers' surplus, where the latter is difference between the amount that consumers would be willing to pay for a given output, given an all or nothing offer, and the amount that they are asked to pay. This quantity is computed by integrating the appropriate demand function.

[6] More detailed discussions of Ramsey pricing may be found in Sharkey, W.W. *The Theory of Natural Monopoly*, Cambridge, UK: Cambridge University Press, 1982; Brown, S.J. and D.S. Sibley, *The Theory of Public*

The Ramsey pricing rule is generally accepted by economists, and in many cases by regulators, as an appropriate methodology for pricing of heterogeneous outputs, as is the case when VDT services are offered in combination with other voice and data services. In the pricing of VDT services, however, it is not appropriate to assume that demand functions are independent. These outputs can be either substitutes or complements for one another, and it is necessary for either a profit or surplus maximizing firm to take account of the relevant cross elasticities of demand. While the simple formulae defined above no longer apply, the derivation of profit and surplus maximizing prices is well understood theoretically, and can be readily implemented given appropriate data. These data include estimates of the appropriate marginal costs and estimates of both own price and cross price elasticities of demand.[7] This information may be difficult to obtain, particularly for new services which would be offered on a broadband network.

There are two potential drawbacks to the Ramsey pricing methodology in addition to the informational requirements noted above. First Ramsey prices may be perceived as inherently unfair, and therefore politically non-viable in a regulatory environment. This follows because the rule requires that the markup of price above marginal cost should be the greatest in those markets in which the elasticity of demand is the least. From the point of view of overall economic efficiency this rule makes perfect sense, since customers with inelastic demands will curtail their consumption less than customers in more elastic markets would. The rule in effect institutionalizes a transfer, or subsidy, from customers in inelastic markets to those in elastic markets. If such a pricing methodology had been applied to traditional telephone services, access to the network and local usage would have borne a significantly larger share of common costs than interexchange toll. It is unlikely that such an outcome would have been accepted by state and local regulators.

The second potential difficulty with Ramsey pricing is related to the potential cross subsidy problem noted above. Just as the Ramsey pricing rule takes no account of the issue of fairness or the potential for cross subsidization among customer classes, it does not account for the possibility of competition in one or more of the firm's markets. It may well happen that markets with inelastic demands are also served by active or potential competitors, who could profitably undercut the Ramsey price. In a fully deregulated marketplace, the presence of competition does not pose any particular difficulties. In this case, the properly interpreted Ramsey pricing rule would take account of the increased elasticity in markets where competitive forces were most vigorous, and

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Utility Pricing, Cambridge, UK: Cambridge University Press, 1986; Tirole, *op. cit.;* and Mitchell, B.M. and I. Vogelsang, *Telecommunications Pricing: Theory and Practice*, Cambridge, UK: Cambridge University Press, 1991.

[7] Cost functions appropriate for broadband telecommunications services are considered in McLean and Sharkey, "An Approach to the Pricing of Broadband Telecommunications Services," (Bellcore TM-ARH-021099). Demand elasticities may be determined from econometric techniques applied to survey data on anticipated demand or to actual data on demand for closely related services.

accordingly set prices in these markets close to marginal cost. In other words, Ramsey pricing consists of "charging what the traffic will bear." In a regulated environment, it may be difficult for this approach to win regulatory approval.

3. Cost Based Pricing

Clearly a firm should pursue a profit maximizing strategy if it is allowed to do so. If the firm is regulated, there are sound arguments for using a Ramsey pricing approach as outlined in the previous section. However, as a practical matter, regulated firms are often expected to set prices on the basis of "fully distributed costs." In this section we will describe a method of cost based pricing that is, in some sense, the most defensible among the various possible methods of cost based pricing.

Cost based pricing takes as given the vector q of customer demands. Rather than attempting to find the outputs q that maximize an objective function based on profit, or social surplus, cost based pricing seeks to determine prices p_i which allocate the total cost $C(q)$ in a "fair and consistent" manner. In this section we demonstrate one method by which very specific pricing rule can be defined precisely by means of plausible properties, or axioms, that one might impose on the set of all conceivable pricing rules. While this section contains more mathematical notation than most other sections, the mathematics is included only for a precise statement of results. The reader can obtain a general understanding of the methodology without necessarily following the details of the mathematical derivations.

The cost based pricing approach is appropriate primarily in the near term future, when telephone companies must argue that it is in society's interest for them to deploy fiber networks which are capable of delivering broadband services. Clearly the question of initial deployment of a broadband network is related to the question of pricing of broadband services after such networks are in place. Since voice, video and data services will share a substantial amount of common plant and equipment in a BISDN network, an important input into the setting of prices is a sensible procedure for the allocation of such costs. Currently accepted cost allocation methodologies, however, do not imply that every ATM cell must be priced identically. In this section we briefly describe how one such cost based pricing methodology is defined.

Cost allocation methodologies can be defined by enumerating "properties" that a reasonable person might want to impose on the set of all possible pricing rules. These properties include ordinary accounting restrictions that are non-controversial, as well as properties that seek to ensure that the pricing rule is perceived as fair. One set of properties that has been extensively studied is the following:

Property 1 (Cost Sharing): Revenues should exactly recover total cost. We note that total cost includes a payment to equity holders in the firm which is required in order to allow them to earn a "fair rate of return" on their investment.

Property 2 (Monotonicity): If an increase in the output of a service unambiguously increases total cost, that service should be assigned a positive price.

Property 3 (Additivity): If it is possible to decompose the total cost of producing a set of outputs into two or more component cost functions, then the pricing rule should be additive over the component functions.

Property 4 (Consistency): If two commodities have exactly the same effect on total cost, they should be charged exactly the same price.

Property 5 (Rescaling Invariance): If units of measurement are changed, then prices should be rescaled in the natural way.

It has been demonstrated that these five properties precisely define a unique pricing rule which has a natural interpretation as an average of marginal costs. The so-called "Aumann-Shapley" pricing rule, which the above properties define, is given by the formula

$$p_i^{AS}(\bar{x}) = \int_0^1 \frac{\partial C}{\partial x_i}(t\bar{x})dt$$

which represents the price assigned to output *i* when the aggregate output vector $\bar{x}$ is produced and C(x) represents the cost of producing any output x. Thus one sees that the Aumann-Shapley price for output i is the average of the marginal costs of producing an additional unit of output i, as outputs are expanded along the path from 0 to $\bar{x}$.[8] We note that it is possible to define other axiomatic pricing rules that are related to Aumann-Shapley pricing. For a full discussion of these rules, and some of the computational issues involved in computing actual prices, the reader is referred to the papers by McLean and Sharkey cited in the footnotes.

When applied to VDT services, the Aumann-Shapley pricing rule defines prices as a function of traffic characteristics such as the frequency of arrival, duration of the call, and the

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[8] A more complete discussion of the Aumann-Shapley pricing rule and its application to some specific cost functions is contained in McLean and W.W. Sharkey, "Alternative Methods for Cost Allocation in Stochastic Service Systems," unpublished manuscript.

bandwidth requirement.[9] Since the costs associated with traffic intensities of services offered on a BISDN consist of congestion and delay for other services, these costs can also be reflected in the cost based pricing approach. Let $q = (q_1, \ldots, q_n)$ represent a vector of n "service classes" (e.g. voice, video, data, etc.). Demands for service arrive at a transmission point consisting of k channels, and for simplicity, we assume that the arrival of a "call" of type i is a Poisson process so that q_i measures the probability that an additional call arrives at any instant of time. Calls contribute to overall system congestion in two ways. First, each type i call has a duration, or size, which is exponentially distributed with mean r_i and variance r_i^2. Second, the cost of providing a service depends on the number of processors that are simultaneously required, and the different protocols required in transmission. Thus arriving calls also contribute to system congestion through the number, d_i, of simultaneous channels which are required for the duration of a type i call.

Several different cost functions can be constructed depending on the queue discipline and the buffer size. Queue discipline refers to the order in which arriving jobs are processed. Buffer size refers to the capacity of the system to hold jobs prior to the commencement of service. Let k represent the number of channels and let B represent the buffer size. Let $g(k,B)$ represent the cost of building a system with k channels and a buffer of capacity B. Typically g is an increasing function of k and B. Given k, B, and the values of q_i, r_i and d_i, let $\beta_i(k,B;q,r,d)$ be the blocking probability for a call of type i. Finally, let $w_i(k,B;q,r,d)$ represent the expected waiting time for a call of type i.

We consider two models which may be used to define a cost function for a general telecommunications design problem.

Model 1: Let $\overline{\beta}_1, \ldots, \overline{\beta}_n$ and $\overline{w}_1, \ldots, \overline{w}_n$ be "acceptable" blocking probabilities and expected waiting times. In this model, the design problem is to minimize the system cost $g(k,B)$ of constructing a facility such that blocking and waiting costs are within acceptable limits. Solving this optimization defines a cost function C as a function of outputs $q = (q_1, \ldots, q_n)$ where each output i is characterized by its service time r_i and its bandwidth requirement d_i.[10]

Model 2: Let c_i be the value to a type i caller if his call is not blocked. Equivalently, c_i represents the economic loss associated with a blocked call of type i. Let γ_i represent the economic loss associated with a unit of time spent waiting in the queue. In this model the system

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[9] Specific functional forms of such pricing rules are contained in the papers by McLean and Sharkey, *op. cit.*

[10] Formally the cost function C is defined by

designer wishes to maximize social surplus, which is equivalent to minimizing the sum of capacity cost plus blocking and waiting costs.[11]

A useful special case of Models 1 and 2 is one in which buffer capacity is equal to zero and server requirements are homogeneous, with $d_i = 1$ for all i. Then the blocking probability is the same for all call types and is given by the Erlang loss formula. The cost functions in models 1 and 2 are then defined by integer optimization problems that can be solved in principle for any vectors of demand parameters q, r, and d. Naturally there are substantial computational difficulties associated with the above approach, and specific pricing rules have, so far, been obtained only for even more specialized situations.[12]

While it does not appear likely that pricing rules based on cost allocation procedures can

$$C(q,r,d) = \min_{k,B} \; g(k,B)$$

subject to

$$\beta_i(k,B;q,r,d) \leq \bar{\beta}_i \text{ for all } i$$

$$w_i(k,B;q,r,d) \leq \bar{w}_i \text{ for all } i$$

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[11] Formally the cost function $C(q,r,d)$ is given by the following expression:

$$C(q,r,d) = \min_{k,B} \left\{ g(k,B) + \sum_{i \in N} c_i q_i \beta_i(k,B;q,r,d) + \sum_{i \in N} \gamma_i w_i(k,B;q,r,d) \right\}$$

[12] See papers by McLean and Sharkey, *op. cit.* The Erlang loss formula which defines the blocking probability is given by

$$\beta(q,r,k) = \frac{(q \cdot r)^k / k!}{\sum_{i=0}^{k} (q \cdot r)^i / i!}$$

Since buffer capacity B is constrained to be equal to 0, there are no waiting costs, and the cost functions in Models 1 and 2 become respectively

$$C(q,r,d) = \min_{k=0,1,2,\ldots} \; g(k) \quad s.t. \quad \frac{(q \cdot r)^k / k!}{\sum_{i=0}^{k} (q \cdot r)^i / i!} \leq \bar{\beta}$$

and

$$C(q,r,d) = \min_{k=0,1,2,\ldots} \; g(k) + (c \cdot q) \, \frac{(q \cdot r)^k / k!}{\sum_{i=0}^{k} (q \cdot r)^i / i!}$$

fully resolve the Robert Pepper conundrum noted in the introduction, the cost allocation approach clearly indicates that average cost per cell pricing is overly simplistic. This follows because the cost function which appropriately models the cost of providing a variety of VDT services depends on the full array of traffic characteristics that characterize the services. Since an Aumann-Shapley price is an average of marginal costs, the Aumann-Shapley pricing rule depends on a complex, and economically meaningful, set of demand parameters, rather than simply on the number of cells which are transmitted.

Cost based pricing rules can be criticized on several grounds. In their most elementary form, as presented above, these rules do not take any account of customer demand elasticities. Furthermore, despite their axiomatic foundations, cost based pricing rules are inherently arbitrary from a purely economic perspective. That is, they ignore traditional concepts of economic efficiency which relate marginal benefits, or marginal revenues, to marginal costs of production. In addition, cost based pricing rules are, by definition, unresponsive to competitive pressures which differ in different markets. Thus cost based pricing rules have the potential for inviting uneconomic entry as in the bypass of the local loop. Finally, pricing rules based on cost allocation procedures do not take any account of the potential for customer arbitrage among services. In the remaining sections of this paper we consider ways in which each of these objections can be appropriately addressed.

4. Subsidy Free and Sustainable Pricing

In a competitive environment demand based pricing tends toward charging what the traffic will bear, while cost based pricing leads to rules which are completely unresponsive to competitive pressures. In a partially regulated but partially competitive environment, some degree of flexibility, but something less than full flexibility on the part of the regulated firm is called for. The theories of cross subsidization and of sustainable pricing seek to establish the appropriate degree of flexibility by setting permissible bounds on prices for individual outputs and collections of outputs.

Thus the theory of "subsidy free pricing" is primarily an application of the techniques of cost based pricing in situations in which there is competition in one or more of the regulated firm's markets. In traditional telecommunications pricing, the allocation of non-traffic sensitive costs associated with the local loop has been a persistent issue. For these costs, it is well known (and well documented) in the literature that all cost allocations are inherently arbitrary, and that reliance on specific fully distributed cost allocation rules in a partially competitive environment can lead to undesirable outcomes, both for telecommunications consumers and for the regulated firm. Nevertheless there exist well established procedures for establishing bounds on permissible cost allocations such that no group of consumers is disadvantaged (i.e. cross subsidized) by any other group of consumers. We will consider these issues in this section.

The fundamental principle of the theory of subsidy free pricing is that no group of customers should pay more for the outputs which they consume than they would if served by a specialized firm devoted to their needs alone.[13] If it is assumed that each product of a multiproduct firm is consumed by a distinct group of customers, then subsidy free pricing requires that no subset of customers pays more than the "stand alone" cost of serving them. If S represents any subset of customer classes and q^S represents the outputs associated with S, then the subsidy free conditions can be written

$$\sum_{i \in S} p_i q_i \leq C(q^S)$$

In addition the firm must continue to break even (including the return to equity holders), so that $\sum_{i \in N} p_i q_i \leq C(q)$. An equivalent way of defining subsidy free prices is in terms of the "incremental cost" of serving any subset of consumers. According to this criterion, every group should pay at least the incremental cost of serving it, so that

$$\sum_{i \in S} p_i q_i \geq C(q) - C(q^{N-S})$$

where q^{N-S} represents the cost of serving all customers other than S. According to this approach, as long as every subset pays enough to cover its incremental cost, any remaining cost can be assigned arbitrarily to any group of customers without violating the principle of fairness implicit in the subsidy free constraints.

To consider a very simple example, let the cost function be given by $C(q_1, q_2) = f + c_1 q_1 + c_2 q_2$, where f represents a "fixed" cost of production, and c_1 and c_2 represent constant marginal costs. Such a cost function is the simplest kind of function in which issues of cost allocation arise. In this case a price vector $p = (p_1, p_2)$ is subsidy free whenever $c_i \leq p_i \leq c_i + f/q_i$ for each service i.. A slightly more complicated but also more realistic example is one in which stand alone cost functions are given as follows:

$$C(q_1, 0) = f_1 + c_1 q_1$$

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[13] This concept clearly is not intended to apply in all situtations. Technically it is appropriate in a technological environment of increasing returns to scale, in which additional consumption by one group of consumers does not necessarily make every other consumer worse off. In a decreasing returns situation (e.g. fishing from a common ocean or drawing water from a common aquafer) different principles must be applied. Even in an increasing returns environment, subsidy free prices may fail to exist, as has been described in Sharkey, 1982, *op. cit.*

$$C(0\,,q_2)=f_2+\;c_2\,q_2$$

$$C(q_1\,,q_2)=f_{12}+\;c_1\,q_1\,+c_2\,q_2.$$

In this case the subsidy free constraints require that $c_1+\frac{f_{12}-f_2}{q_1}\le p_1\le c_1+\frac{f_1}{q_1}$, and that a similar constraint hold for p_2.

In the pricing of VDT services it is likely that various parties will argue that customers of narrowband services are subsidizing customers of newer broadband video and data services. In order to effectively refute such arguments it may be necessary to construct the appropriate hypothetical cost functions in order to demonstrate that whatever pricing approach is ultimately taken it is true that POTS customers are not being asked to pay more than their stand alone cost. These arguments can be made in terms of the simple cost function defined in the above paragraph.

In a free entry environment, in which all potential entrants have access to the same technology, embodied in the cost function $C(q)$, subsidy free prices also correspond to "sustainable" prices. Sustainable prices are defined as prices that do not invite (uneconomic) entry. This is easily seen by referring to the stand alone test for cross subsidization. If the stand alone test does not hold for a particular subset S of consumers, then it would be possible for an entrant to choose alternative prices $p_i' < p_i$ for each customer i and still make positive profits. Of course, this kind of entry will occur only if entry barriers are extremely low and customers are highly responsive to possibly small price differences–conditions that do not necessarily apply in telecommunications markets. Nevertheless, the theory of subsidy free pricing defines a framework for pricing in the presence of competitive pressures that may be useful to apply in the pricing of VDT services.

5. Non-Linear Pricing and the Arbitrage Issue

A non-linear price structure is one where a consumer's bill is not proportional to the amount he purchases. Billing structures consisting of a fixed monthly fee and a fixed usage charge per unit are non-linear, as a doubling of the units purchased will not result in a doubling of the bill. The prices structures for most telecommunications services are non-linear.

A brief history of the forces responsible for the widespread use of nonlinear prices provides some insight into the arbitrage possibilities that may arise when VDT is implemented. The nonlinearity is often a consequence of the telephone company's need to offer volume discounts to its large users. This need arises from the fact that the costs of networks (or the facilities that comprise them) are largely fixed and the variable costs associated with providing service on a network that is in place are comparatively small. As a consequence, a tariff structure like MTS with usage sensitive charges will necessarily be more expensive than a dedicated facility for a consumer with a sufficiently large volume of use. This fact explains much of the bypass experienced in the industry. Earlier, the bypass was limited to large firms that formed private networks. It is worth stressing that the alternative available to large users involved large fixed costs and no usage related costs, and that this alternative was typically available on a point-to-point basis. AT&T initially sought to prevent bypass to private facilities by pricing private line services attractively. As AT&T private lines were provided out of existing facilities that were installed to meet future demand growth, the additional cost of providing these lines was close to zero, and uneconomic bypass and revenue erosion were largely prevented. The choice between MTS and private lines resulted in a non-linear price structure, as large users on private lines paid a smaller price (on average, and for additional calls) than did those on MTS.

Volume discounting of switched services was developed along similar lines. MCI introduced its Execunet tariff with the intention of sharing facilities across medium to large users whose traffic was not concentrated in a few routes. AT&T developed WATS service to appeal to the customers who might find Execunet better than either MTS or private line services. The widespread availability of WATS service led to the first major wave of aggregation and resale. It was relatively easy for WATS resellers to set up operations based on inexpensive PBXs which allowed subscribers to dial in, authenticate themselves, and then dial out on a WATS line that connected them to their called party over the public switched network. The extent of this resale market was probably unanticipated by AT&T. At its peak, there were more than 1,000 WATS resellers. Most have since gone out of business. A factor that probably played a large part in the death of this industry was the decision by AT&T and the other long distance companies to flesh out their product line by offering a range of options to smaller customers. ProAmerica (later ProWATS) and other new products like Reach Out America and MCI's Friends and Family have reduced the difference in the unit prices paid by large and medium customers, and reduced the incentive to arbitrage. Nevertheless, these differences persist, and some resellers continue to serve niche markets.

Currently, arbitragers appear to have shifted their focus to profitable opportunities created by Multi-Location Calling Plans (MLCPs). These tariffs are designed to meet the needs of customers with offices in many locations, none of which is large enough to benefit from the volume discounts in tariffs such as AT&T's Megacom or ProWATS. The MLCP allows the firm to enroll all its locations in the plan, and compute its discount based on the total volume. MLCP resellers take advantage of this tariff by aggregating customers into collections with enough aggregate volume to benefit from the volume discounts, and jointly applying for a MLCP account. This business is estimated to amount to more than $1.6 billion per year.

The ability of large users to bypass the public network implies that the telephone company can prevent uneconomic bypass only by developing volume discounts aimed at the very largest users. The ability of arbitragers to profitably resell bulk offerings requires a fleshing out of the product line, with options aimed at a larger set of medium sized customers. The use of volume discounts is likely to remain important in the VDT environment. It is likely that large suppliers of video services will face bulk tariffs for switched bandwidth that offers them connectivity to their subscribers. Unless a range of pricing options suitable for medium sized users is developed, resellers may have the incentive to engage in arbitrage of the sort described above. The implication of potential arbitrage is that details of the price structure will matter.

One important question that needs to be addressed is: will some form of bundling be used? Will voice, video, data, image and multimedia traffic each be tariffed independently or will packages encompassing more than one service/application be offered? Video suppliers may purchase a package of transmission services to handle voice, data and video traffic, just as FTS2000 was a package specifying transmission services that could support these applications. The chosen approach will determine important features of market segmentation, and possible entry by arbitragers. Price structures which offer separate discounts for voice and data (for example) will appeal to customers who have large volumes for either data or voice or both, but not those who have the same total volume of use, but moderate volumes of each use. Discounts based on total volume across all uses may induce users with high volume in one use, but relatively lower total use, to seek specialized service from competing providers. Should separate discounts for bundled and unbundled services be offered simultaneously? The question needs greater study.

Another important question concerns the form in which volume discounts are offered. Should volume discounts be offered to customers who presubscribe to the appropriate plan, and pay one time installation charges and high monthly fees, or should incremental discounts be offered automatically to customers whose use exceeds prespecified levels? The former approach places the risk of making the wrong choice on customers. The BCC will benefit in every billing period in which the customer's usage deviates from the range appropriate for the selected plan, and this is a major advantage of the presubscription approach for the BCC. On the other hand, the risk may be sufficient to drive customers to other service providers, possibly including arbitragers who purchase bulk service from the telephone company and aggregate users in order to minimize the risk.

A good deal of work has been done on the development of optimal volume discounts, and some of it is incorporated in user-friendly software tools developed by Bellcore for the owner companies. In addition, some theoretical work has been done on the issues of bundling and presubscription, and this has been incorporated in the software tools. These tools together with market research can provide useful insights into the revenue potential of different pricing structures.

We have argued that the development of nonlinear price structures has been motivated largely by competition for large users, and has resulted in profitable arbitrage opportunities for resellers. Much of the theory of nonlinear prices considers the efforts of a monopolist to segment his market through the use of selective discounts. A recent preliminary paper by Sharkey considers the sustainability of these prices in a competitive market where all firms have identical cost structures and there are no transactions costs associated with marketing services.[14] The main result of the paper is that nonlinear prices will not be sustainable. Competitive firms will seek to reduce market share among those groups paying a low average price by raising the price to these groups, and will compete for market share among groups paying a high average price by lowering the price to them. This will unravel the nonlinear price, and all groups will pay the same price in equilibrium.

This result is critically dependent on the assumptions that all firms have the same cost structure, that there are no marketing costs and that there are no quality differentials across firms. The Sharkey model therefore suggests that the specific ways in which these assumptions are violated will determine the form of nonlinear pricing that will emerge in competitive equilibrium. A clear understanding of cost differences across firms and the marketing costs associated with reaching consumers with limited information is therefore a topic in need of additional research.

6. Priority Pricing and Preemptive Pricing

VDT will not emerge in isolation. It is likely to be introduced contemporaneously with a number of other high bandwidth services aimed at meeting other needs. These services will coexist with a number of existing high capacity services that meet the voice needs of existing customers. New forms of arbitrage may well emerge across these service classes.

Consider, for example, the possible forms of competition between residential video and aggregated voice services. One potential way of offering VDT services to residential customers is to offer them T1 speeds over the local loop using ADSL technology. If this service is to be successful, it must be priced at roughly the levels charged by CATV providers, at about $30-50 per month. Currently, intraLATA T1 lines are tariffed at roughly $500 per month. The discrepancy in price between these two services appears to offer some arbitrage opportunities. These are mitigated by the fact that T1 service usually includes channelization of the available bandwidth and is full duplex, whereas ADSL technology is half duplex and not channelized. Nevertheless, the difference in price may induce the development of PBX options that allow business customers

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[14] W.W. Sharkey, "Strategic Non-Linear Pricing," unpublished manuscript.

to obtain T1-like service on two ADSL lines for a monthly saving of $400. In addition, telephone companies may be required by regulators to justify the very large price differences between what appear to be comparable services offered to different market segments.

There is now a large literature on the optimal design of product lines where any one product on the line can substitute for other members on the line. This literature has significant implications for the pricing of services aimed at different applications.

Consider the provision of applications such as telephony, electronic mail, video services, remote access to host computers, and distributed processing. These applications have differing requirements for underlying network attributes such as security, bandwidth, lost cells, delay and delay variation. Thus, voice can tolerate a cell loss probability on the order of 10^{-4}, while interactive compressed video requires that the loss probability be on the order of 10^{-10} for acceptable Quality of Service (QOS). Delay and delay variation criteria for voice and video transmissions are roughly 10 milliseconds. File transfer can often sustain delays on the order of 10 seconds while meeting QOS.[15] There is therefore considerable heterogeneity in applications' needs for network attributes.

In addition, different customers have differing willingness to pay for these attributes. If the network owner is allowed to integrate vertically into the provision of applications such as electronic mail and video services (i.e. provide content as well as distribution), and if the technical interfaces presented to the customers do not allow for easy substitution across services, then each service can be priced in accordance with the theory of multiproduct monopoly. This theory has been well studied.[16] QOS for each service can be ensured through the use of appropriate congestion control systems. This approach would be sustainable only if the network provider could ensure that a line purchased for a particular application (say video conferencing) is not used instead for another application (say tying together two PBXs). As the price per cell is not constant across applications, this kind of arbitrage may be attractive to some customers; and the losses due to arbitrage may be too large if enforcement is not possible. An open question is: should telephone companies seek regulatory support for heavy penalties for "misuse" of service offerings on the grounds that arbitrage will not allow for cost recovery through efficient market segmentation? What arguments would support this position?

More difficult choices must be made in the current U.S. context, where line of business requirements may preclude network providers from integrating vertically into all stages of production in the information services industry. It is possible that the network operator may then

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[15] See Hong, D. and T. Suda, "Congestion Control and Prevention in ATM Networks." *IEEE Network Magazine*, July 1991, p. 11.

[16] See for example Brown and Sibley, *op.cit.*

be limited to providing access and transport services alone. Even though all applications run on the same network, their differing requirements for QOS can be supported by offering a product line of access and transport services, each product in the line offering different qualities in dimensions such as cell delay, cell loss and priority. Differential prices can then be justified on the basis of differential costs associated with different QOS. An important question is : can a ***self-selection scheme*** be used to segment the market in an economically efficient way? The literature on product line pricing provides a useful framework for the analysis of this issue. Important papers include works by Mussa and Rosen[17], Srinagesh and Bradburd[18], and Srinagesh, Bradburd and Koo.[19]

One theme that can be found in these papers is that efficient cost recovery requires that the offered spectrum of qualities be wider than a narrow technical analysis would suggest. Mussa and Rosen showed that this expansion of the product set required that the highest quality application be provided with undistorted quality. All other applications should face degraded quality. Srinagesh and Bradburd showed that there are plausible circumstances where it is optimal to provide lowest quality applications with undistorted quality, and to provide superfluous quality to all higher quality applications. Srinagesh, Bradburd and Koo develop another model of customer behavior in which it pays the firm to offer undistorted quality to consumers in the middle of the spectrum, with quality degradation of lower qualities and quality enhancement of higher qualities. The factor that determines important properties of the optimal product line is the correlation between marginal and total utilities across customers. Primary market research on the distribution of willingness to pay across the potential customer population is therefore a critical input in determining the efficient product line. In this context, technical differences between offerings that look superficially similar but are aimed at different market segments may well be justified. It may be a virtue of ADSL that its T1 speeds can be used for voice aggregation only at considerable cost.

Many congestion control strategies currently under discussion, such as call control procedures for the set-up of virtual connections, and flow control procedures, provide a basis for the implementation of product line pricing of services.[20] Most preventive congestion schemes for connection-oriented networks are based on the notion of a *traffic descriptor*[21] that captures the

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[17] Mussa, M. and S. Rosen, "Monopoly & Product Quality," *Journal of Economic Theory*, 1978, 301-17.

[18] Srinagesh, P. and R. Bradburd, "Quality Distortion by a Discriminating Monopolist," *American Economic Review*, 1989, 96-105.

[19] Srinagesh, P., R.Bradburd, and H-W. Koo, "Bidirectional Distortion in Self-Selection Problems," *Journal of Industrial Economics*, March 1992, forthcoming.

[20] See Hong and Suda, *op. cit.* and Vakil, F. and H. Saito, "On Congestion Control in ATM Networks." *IEEE LCS Magazine*, forthcoming.

[21] See Vakil and Saito, *op. cit.*

(statistical) effect of the call on congestion (or network utilization). Examples of traffic descriptors are peak bandwidth requirements, peak to average bandwidth ratios (or burstiness) and duration of burstiness[22]. The literature on congestion has not yet provided a definitive description of this important variable. Call control schemes typically formulate conditions under which a call with a particular traffic descriptor should be accepted.

The traffic descriptor can also be used as a market segmentation mechanism. In particular, we can conceive of different grades of service as being defined in terms of the treatment by the network of calls with different traffic descriptors. While the engineering view of congestion control focuses on the issue of fairness in handling calls, the economic view would focus on treating different calls differently, with higher priority given to higher priced calls. This scheme could be the basis for successful product line pricing if traffic descriptors correlated well with willingness to pay. A more general view would make call connection parameters one element of a broadly defined QOS measure.

Another alternative may be to directly mark high price cells with a priority marker.[23] In this scheme, the issue of priority would not be handled only during call set-up, but also during the progress of the call itself. One advantage of this procedure is that it will work for a network that handles both connection-oriented and connectionless traffic. Yet another alternative, suggested by Egan[24], is to use the signaling system to indicate high or low prices based on network congestion, and allow the customers to modulate offered load in response to the price signal. Egan also suggests the use of interruptible service contracts which block (at least partly) some large users' low priority traffic during congested periods.

In conclusion, we stress two points. It is important to understand the elements of QOS that matter for customer satisfaction if effective market segmentation strategies are to be implemented. It is also important that switch design (buffer management and call acceptance protocols) be guided by the economics of market segmentation. These issues need to be addressed in the context of VDT, which offers a very low price per cell compared to other transport mechanisms.

7. Incentive Pricing with Incomplete Information

In general, the price of a product should take into account: (i) the costs of manufacturing and supplying it; (ii) the customers' willingness to pay for it; and (iii) the market structure of the industry in which the product belongs and the prices and output choice made by competitors; and

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[22] Hong and Suda, *op. cit.*

[23] Hong and Suda, pg. 14-15.

[24] Egan, B., "Costing and Pricing the Network of the Future," *Proceedings, IEEE*, ISS,1987, 483-90.

the potential for entry into the industry. The choice of an optimal price depends on the firm's knowledge about the many economic parameters underlying these factors. Typically, this knowledge is incomplete. In the absence of a mechanism to gather or elicit information that enhances the firm's knowledge base, the price structure can be inefficient, and the firm could be foregoing significant profit opportunities. These issues arise in the pricing of VDT services.

To give an idea of the kind of mispricing that can occur because of incompleteness of information, we shall focus on one of the factors listed above. We shall assume that the BCC is fully informed about its own costs and technological parameters and about its competitors; however, it cannot directly verify the willingness to pay by customers. An obvious approach to bridging this gap is for the BCC to conduct market surveys to ascertain these values for the different services to be offered on the VDT platform. The information gathered from such surveys is likely to determine not only the tariffing of the services, but also the level of investment in the new fiber optics network.

Typically, a customer's willingness to pay for a service is determined by the benefits derived from the service. Consider the following scenario. The BCC representative plans to conduct a census of a hundred customers in a given area by asking them to report the amount they are willing to pay in terms of an increase in current telephone rates to help towards building a broadband network. Let i be an index for a typical customer; thus, i could take on values 1,...., 100. Each customer obtains a private benefit of B_i, which could be expressed in terms of dollars and can be interpreted as customer i's "true" maximum willingness to pay. The customer's reported willingness to pay is denoted R_i. Suppose it is known that the cost of building the network to serve the community in question is $1 million. Also, it is known that this cost has to be fully recovered by increases in current rates. The increases are expected to be in proportion to their reported willingness to pay. If everyone were to report that they are willing to pay $0 then the network is not built, and the project is shelved. Once the network is built, then, of course, no one can be denied access to the services it provides regardless of whether they indicated a willingness to share in the cost of its construction.

Thus, suppose that customer i reports that he is willing to pay $100 and customer j reports that she is willing to pay $1000, and the sum of the reports made by all hundred customers is $10,000. In this case, customer i will be charged a price equal to $1 million × 100/10,000 and customer j is charged $1 million × 1,000/10,000. On the other hand, customer k reports that he is willing to pay $0 and, therefore, pays nothing. Such a cost allocation scheme which is in proportion to reported willingness to pay is standard practice. (For example, financing of public radio or television programming by voluntary contributions allocates costs in proportion to willingness to pay.)

Suppose that the sum of the true benefits B_i far exceeds the cost of building the network, i.e. $B_1 + \ldots + B_{100} >$ \$1 million; hence, the network clearly has positive value. On the other hand, it is reasonable to expect that for any i, $B_i <$ \$1 million; hence, no customer will find it worthwhile to finance the network by himself. How do we expect the customers to report? From the standpoint of any individual customer, it is never rational to report any willingness to pay other than \$0. This is true regardless of what the other customers may have reported. To understand the argument behind this, consider the following simple reasoning on the part of customer i: "If no one else reports a positive number, then the network is not built, and my payoff (in dollars) is zero. But announcing a positive R_i would yield a negative payoff of B_i - \$1 million, since I would have to finance all of it. If the network is built (i.e. some other customers do report positive values) I will obtain a payoff of B_i if I report \$0 and $B_i - R_i/(R_1 + \ldots + R_{100})$ for any positive R_i report. So in every conceivable instance, it is a "dominant" strategy for me to report $R_i =$ \$0." Every customer rationalizes a report of \$0 in this manner, and the network is not built, even though everybody could have benefited from its presence.

The example above is, of course, an extreme case. However, the main point it makes is applicable in all other situations involving incompleteness of information about the preferences of customers: the pricing or cost allocation rules will not be efficient.

The economics literature has expended a considerable amount of energy in tackling the problems associated with incompleteness of information. This area is broadly referred to as the theory of mechanism design and it finds applications not only to questions relating to allocating the costs of a proposed fiber optics network, but also to the development of flow control algorithms and prioritizing users of the network once it is in place.

Once again, instead of giving a broad survey of the literature on mechanism design, we shall try to show how the information gap is bridged by devising pricing schemes using a simple example of allocating customers on a broadband network.

Suppose that the network is to be used by different types of customers ranked from those with the highest priority to those with the lowest priority. The priority levels are private information to the customers and the network administrator cannot observe them. Also, as is evident, it is too costly to audit the customer to obtain an accurate reading of the appropriate priority level. The differences in priority levels translate to differences in marginal utilities to the customers from being allocated a particular arrival rate onto the network, and marginal disutilities from the delays generated due to congestion. We shall formalize the argument as follows.

Suppose that each customer accesses the network at a rate q_i. The aggregate effect of all the customers attempting to use the network is that it leads to a delay, denoted D. Each customer i is characterized by a utility function which is dependent on q_i and D given by $U_i(q_i, D)$. This function is increasing in the first argument and decreasing in the second for all customers; however, for all values of q_i and D, the absolute values of the partial derivatives $\partial U_i/\partial q_i$ and

$\partial U_i/\partial D$ are higher for higher priority customers.

The utilities of the customers obtain after a network is built translates into a commitment to pay for the network before it is built. Hence, the network provider's objective is to maximize the sum of the utilities $U_i(q_i, D)$ over all i. This is expected to maximize the aggregate amount that the BCC can expect to raise up front to build the network.

We can imagine the BCC, as a network provider, requesting information on the values of $\partial U_i/\partial q_i$ and $\partial U_i/\partial D$ from customers and then adjusting the access rate for each customer in a way so that the objective of maximizing $\sum_i U_i(q_i, D)$ is met. Assuming that the network capacity constraint does not restrict choices, the optimal access rate $q^* = (q_1^*, \dots, q_n^*)$ is achieved when $\sum_i U_i$ can be increased no further. This occurs if $\frac{\partial}{\partial q_i}[U_i(q_i^*, D)] = 0$ for all i. Of course, the BCC has no direct knowledge of the customers' true values to determine q^*. To provide the right incentives, the scheme must involve monetary transfers between the users. A variety of transfer schemes can be devised which elicit either the truthful information or just enough information to calculate the optimal level of delay and the allocation of rates across the customers. These transfer schemes work in conjunction with an algorithm that controls the rate allocation as a function of the reports. The transfers are side-payments between the customers and involve no subsidization from the BCC to its customers. Transfers among customers can be implemented in the real world through various kinds of targeted rebates or credits to specific classes of customers.

8. A Reexamination of the Arbitrage Issue

Even with appropriately designed non-linear and priority pricing methodologies we suggest that it may not be possible to entirely eliminate arbitrage opportunities by technological means alone in the long run. Despite the ongoing research on pattern recognition systems that distinguish various forms of traffic, to date we do not know of one that can actually be deployed in the field. Moreover, even if one is developed in the future, a clever entrepreneur could always fool the system. Whatever pricing rule one adopts, eventually it must be competitive, and, therefore, on a per cell basis, a video packet will be heavily discounted relative to a voice packet. Voice signals might be aggregated and packaged so as to resemble a video transmission, assuming that detection by traffic distinguishing methods is imperfect. As a result video channels could be used to carry voice traffic at a price that is significantly lower than that being charged by a local operating company.

A second constraint is that the pricing structure cannot be made arbitrarily complex, as is the case with, say the pricing of airline services. Telecommunications customers will not tolerate a tariffing system which requires a translation by a computer or an agent (similar to a travel agent). The implication of this is that classical economic pricing rules based on marginal cost may not be practical. The marginal cost of a signal in a telecommunications network is basically the cost imposed on the network due to addition to the level of congestion. Congestion, in turn, depends on the rate of arrival of cells that constitute a "call", the duration and the number of channels used up, and the composite effects these attributes have on an alternative call being blocked or delayed or re-routed. Since the probabilities of such occurrences are constantly changing, the prices should, strictly speaking, be changing in response. For practical reasons, the prices are set on a much coarser grid to accommodate the customers' aversion to complexity. The best that can be done is that the grid is designed to be a crude proxy for the marginal cost. Moreover, due to externalities between different services on the same broadband platform, the technological parameters do not fully account for the true economic costs. In sum, practical limitations on the pricing structure for services over a broadband network may lead to sub-optimal outcomes for both service providers and their customers.

The approach suggested here is that the BCCs might want to consider a drastic re-definition of what they mean by a customer. By providing a network that in one fell swoop rivals print, radio, electronic and visual media, they are likely to attract an entirely new class of customers who have virtually limitless budgets (over 3% of the GNP), and who have no established pattern of dealing with the telecommunications industry, and, therefore, are likely to be open to innovative pricing schemes. This is the advertising industry. The current hostility of the anti-Bell lobby (spearheaded by the newspaper industry) is driven precisely by the projection that the broadband network will be the advertising medium par excellence, if it takes off. Potential BCC customers of tomorrow fall into two classes: direct users of the network and indirect users who transmit advertising information.

In all the calculations about what the market is willing to pay for a service, both classes of customers should be included. It can be argued that the explicit inclusion of this new category of customers serves four important purposes: (i) The first and most obvious one is that it brings in additional revenue. (ii) It can partially alleviate the arbitrage problem. Voice customers will typically not tolerate advertisements over their conversations, whereas video customers are more tolerant. A video channel can be designed to carry a constant stream of advertising signals, which would deter re-packaging. (iii) The tariffing structure can be made to conform to a finer grid and a closer approximation to true marginal costs. This complexity is passed on to corporate sponsors who will book advertising space in much the same way as airline seats are reserved nowadays. A centralized booking office will be required. (iv) Finally, the indirect users will subsidize the direct users, which in turn will make the broadband network more competitive. This will feed back into an upward shift in the demand by indirect users, and lead to an upward spiral in profitability.

Although this discussion is preliminary in nature, it suggests a useful research strategy for telecommunications companies in the early stages of broadband deployment. Instead of focusing on the traditional customer base and polling them in market surveys to determine the viability of a broadband network, the effort should be to a large extent be re-directed to determine the willingness to pay by advertisers for transmission of a broad category of services. The current plans are to use the traditional telecommunications customer data as the basis for establishing appropriate pricing and marketing strategies. We argue that the data are quite inadequate and give only part of the picture; in fact, it may even be the less important and less flexible part.

9. Pricing Theory in the Real World

As was stated in the introduction, there is no single pricing methodology that is best in all circumstances. In this paper we have attempted to outline the approaches that economic theory suggests to be most relevant in pricing broadband telecommunications services. Four specific methodologies were considered: (i) demand based or Ramsey pricing (including profit maximization as a special case), (ii) cost based pricing using the Aumann-Shapley pricing rule (or one of its variants), (iii) non-linear and product line pricing, and (iv) priority and preemptive pricing. These rules are not mutually exclusive. For example, non-linear pricing can be implemented by differentiating customers in a quality dimension in which priority and preemptibility of service are important attributes. Furthermore, priority of service can, in principle, be incorporated into the cost based pricing methodologies, since costs of serving different customer classes will depend on their priority level.

In order to give a short answer to how these results should be utilized, we offer the following suggestions. Since we have identified the arbitrage problem as the greatest single obstacle to implementing reasonable pricing rules that will serve the interests of BCCs and their customers, we suggest that primary attention be given to the design of product line pricing strategies that will serve to mitigate the arbitrage problem to the greatest extent possible. We also suggest that new revenue sources, such as from advertising media, should also be explored in this context. After a careful consideration of the appropriate definition of products to be offered and markets to be served (both of these will rely on extensive marketing analyses) it may still be necessary to determine relative prices for products within a given class. For example, if electronic mail and voice communications have the same priority characteristics, a method must be found to determine their relative prices. For this purpose, the profit maximizing approach is clearly optimal from the BCCs point of view, but it is not a feasible approach in a regulated setting. Both Ramsey pricing and Aumann-Shapley pricing are appropriate tools for setting relative prices for a regulated firm. Both are readily implementable as soon as an adequate description of the cost of providing service is known, and in the case of Ramsey pricing, as soon as estimates of demand elasticities are available.