The Secondary Market for Capacity in Natural Gas Transportation

Rigoberto Ariel Yépez

Abstract: The purpose of this paper is to consider the problem of allocating the costs of a public facility with large fixed costs and increasing returns to scale. A particular case is considered for the natural gas transportation industry. A model for allocating capacity over time is considered. The approach is to find optimal pricing so that social welfare is maximized while the common facility is efficiently used. If individuals have property rights to the capacity of the common facility, the result of the analysis leads to the existence of market-clearing prices through a secondary market for the capacity of the common facility.

Resumen: El objetivo de este documento es considerar el problema de asignación de costos de un bien público con costos fijos y rendimientos crecientes a escala. En particular, se considera el caso del transporte del gas natural. Se desarrolla un modelo para la asignación de la capacidad a través del tiempo. El objetivo del modelo es encontrar los precios óptimos que maximizan el bienestar social a la vez que se utiliza eficientemente la infraestructura. El análisis muestra que si los agentes económicos tienen derechos de propiedad de la capacidad de la infraestructura común, entonces se tendrán precios de equilibrio en el mercado a través de un mercado secundario para la capacidad del bien público.

When comparing alternatives in providing natural gas transportation service, it is important to consider the overall costs of transportation, including capital and maintenance and operating costs. The choice between the different production factors, if an optimal level of efficiency is to be attained, must be selected considering their relative prices and marginal productivity. The cost structure of the natural gas transportation industry can be characterized as one with large fixed costs. Once a pipeline has been constructed, the capital costs are "sunk" costs, fixed and independent of the usage level of the pipeline.

The cost of installing a public facility and the investment required to maintain it are very large and highly independent of its utilization, rendering the costs associated with pipelines to increase less than proportionally to usage. Furthermore, since a single pipeline can serve a large range of users before its capacity is fully used, investment in pipe is both short- and long-run indivisible, and therefore huge fixed costs will be spread over a large number of output units as the pipe usage is increased.[1]

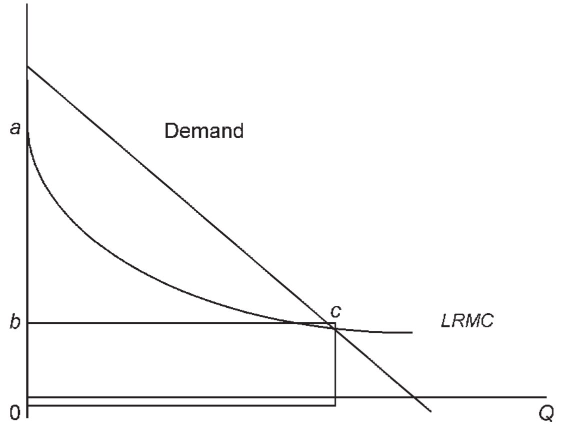
In addition to the previous facts, due to the increasing returns to scale in the industry's production technology, it follows that long-run marginal cost is less than the long-run average cost per unit.[2] Therefore, using marginal-cost pricing would lead to a deficit for the firm. In such a case, the firm would not break even and would require a subsidy to cover the deficit in order to continue production, necessitating a redistribution of income from non-users to users of the service. As can be seen in Figure 1, if the demand curve intersects LRMC while it is declining, charging customers only long-run marginal cost will produce a loss to the firm, as denoted by the triangle *abc*. Hence using marginal cost pricing will not allow a pipeline company to break-even. In fact, under the constraint of full allocation of cost, the optimal natural gas transportation rates will exceed marginal cost.

If the deficit introduced by marginal cost pricing is covered by subsidization, it will cause inefficiencies due to price distortions and resource misallocation. Therefore, the efficiency of marginal-cost pricing will be questionable whenever a non-user is forced to pay for a public facility. In consideration of this problem, Coase (1946) made the observation that users must pay the full cost of receiving a service

[1] Indivisibilities lead to decreasing costs, since once the pipeline has been constructed, any amount of gas to the limit can be transported through the pipe.

[2] Ariel Yépez (1994), *A Cost Function for the Natural Gas Transmission Industry. Applied Price Theory Workshop*, University of Chicago, April.

Figure 1. Decreasing marginal cost



to achieve efficiency. Coase stated that not only should the cost of producing the marginal unit be covered by its price, but also that the cost of all units should be covered by payments from users. Following his argument, we see that if the price a user pays does not cover the total cost of his demands, then there are some factors used in supplying him which are not being accounted for in the price. The use of these factors is therefore not being economized and efficiency is not obtained. In other words, if someone does not wish to pay the total cost of supplying his own demands, the value in his use of the factors used to supply him is less than what their value would be in some other use.

Welfare and fairness problems open the question of how to charge each customer his fair share of the cost and still ensure that the firm will break even. One way to deal with these problems is by looking for methods where all cost of the public facility are met by payments from its users, providing fair and non-discriminatory charges under some criteria.

Cost Allocation

Three related questions may be settled before an agreement to build a public facility. These questions have to do with the number of users of the facility, the optimal size of the facility, and the charge scheme for covering the total costs of the system. Once the project has been designed optimally to satisfy the necessities of the users, one problem that arises is how to commit agents interested in receiving the service of the public facility to cover the cost of the facility over its lifetime.

Long-Term Contracts

In most of the cases public facilities are large investments in specialized, immobile and market-specific capital. These particular characteristics, as well as the vulnerability to be affected by fluctuations in economic activity, may affect the long-term relationship between public facility users and the facility owner.

The eventuality of a fall in the capacity demanded from a facility may threaten the ability of the facility company to recover the cost of its investment. On the other hand, the possibility of a shortage will affect the interests of customers who wish to have a secure capacity of the public facility in sufficient quantities to meet their current and expected necessities. Situations such as these, which generate uncertainty among the agents in the facility industry, will lead these agents to seek out opportunities to arrange long-term agreements that efficiently allocate the risks they would be facing over time.

Hence, the size and financial risks involved in the construction of a public facility, together with the risks of inefficient bargaining and opportunistic behavior, dictate the necessity of long-term contracts to protect long-term investments in the facility. Otherwise, the convenience of developing a project may be threatened by the uncertain ability of the firm to cover the cost of the system over its useful lifetime.

The economic literature on this efficiency approach asserts that long-term contracts may help to distribute risks in a socially efficient manner in situations with specific and immobile capital. As Telser argues:

> Long-term contracts between suppliers and their customers such as the take-or-pay contracts in natural gas are arrangements that restrict competition [...] these restrictions advance the public interest by preventing exploitation of those who have incurred large fixed investments that raise efficiency and thereby accommodate their customers (1996, p. 86).

The case of the natural gas transportation industry is one of those where this kind of agreements are necessary. Long-term contracts benefit the pipeline companies by reducing the financial risk of non covering their fixed costs and by decreasing the possibility of a shortage for consumers. Furthermore, they eliminate the expense and uncertainty of frequent rate reviews. Thus both the pipeline company and the consumers will be willing to enroll in long-term agreements that allocate the risks inherent to any economic transaction in the natural gas industry. However, long-term contracts can involve substantial costs. Since contracts reduce the flexibility to react to market supply and demand conditions, the greater uncertainty associated with distant horizons can make inflexible pricing particularly hazardous, affecting the willingness of each signer to perform as promised in the long-term contract.

Allocation of Capacity over Time

Due to changes in the performance of the agents concerned with the facility, a problem that may arise is the possible presence of incompatibilities in the demand and supply for the facility capacity over time. As time elapses, after the facility is functioning, some owners of the capacity rights of the facility may be sub-utilizing their reserved capacity, while other users may require additional capacity. For instance, in the case of the natural gas transportation industry, the dynamics of the natural gas industry will require the existence of a market that helps shift capacity where it is most needed, ensuring that no higher-valued users are deprived of gas and that capacity owners receive true market value for their rights. The creation of such a market will benefit capacity users if they can sell their unneeded capacity and thereby reduce their obligation to pay the higher reservation cost associated with the long-term contract.

A market for capacity would permit users to negotiate an assignment of capacity that reflects the services that users need from the public facility. In such a framework, current owners of the capacity of the facility would be able to sell their capacity rights in an organized capacity market to users who had already been utilizing the services of the facility, or, alternatively, to outsiders who could buy the capacity rights for their own use.

The following model considers the market approach to capacity allocation over time. It attempts to simulate the behavior of agents who use the common facility during different periods of time, given that the capacity of the facility is constrained. The approach is to find optimal pricing so that social welfare is maximized while the common facility is efficiently used.

The Model

Consider the case in which a group of consumers $N = \{1,.., n\}$ wishes to share the service of a pipeline with a limited capacity Q. Let q_j^i be the capacity used by individual i ($i = 1,.., n$) at time j ($j = 1,.., t$). Also let $q^i = (q_1^i,..., q_t^i)$ be the vector (of dimension t) of capacities used by the agent i over all the periods of time. Suppose also that each agent has a valuation function $V^i(q^i)$ that represents the maximum that individual i would be willing to pay for consumption q^i ($V^i(\bullet): \Re^t \to \Re$). Furthermore, assume that $V^i(q^i)$ is a non-decreasing concave function with continuous first-order partial derivatives. Agents are further required to have initial ownership of the capacity of the pipeline. Let $y^i = (y_1^i,.., y_t^i)$ designate the vector (of dimension t) of initial endowments of capacity of individual i over all periods of time.

The objective is to maximize the sum of consumers' valuations of the capacity of the common facility, given the following physical feasibility constraints:

$$\sum_{i=1}^{n} q_j^i \leq \sum_{i=1}^{n} y_j^i, \quad \forall j \tag{1}$$

$$\sum_{i=1}^{n} y_j^i \leq Q, \quad \forall j \tag{2}$$

Constraint (1) means that, for each period of time, the capacity allocated to agents is lower than or equal to the total initial endowment of capacity in each time period. Constraint (2) represents the fact that total initial endowments cannot be larger than the capacity of the system in each time period.

The social welfare maximization problem can be expressed as:

$$Max \sum_{i=1}^{n} V^i\left(q^i\right) \text{ with respect to } q^i \geq 0 \; s.t. \sum_{i=1}^{n} q^i \leq \sum_{j=1}^{n} y^i \tag{3}$$

It must be noted that the constraint denotes an inequality between the vector of demand of capacities and the vector of total endowments; hence each element in the vector represents the capacity constraint in each period of time. The Lagrangian for this problem is:[3]

[3] Since $y^i, q^i \in \Re^t$, the vector of Lagrange multipliers, λ, has dimension $t (\lambda \in \Re^t) \cdot q \cdot y = \Sigma q_i y_i$ denotes the inner product of the vectors q and y.

$$\Im = \sum_{i=1}^{n} V^i\left(q^i\right) + \lambda \cdot \left(\sum_i y^i - \sum_i q^i\right) \tag{4}$$

Differentiating with respect to q^i and λ, the solution must satisfy the following conditions:

$$\frac{\partial \Im}{\partial q^i} = \nabla V^i - \lambda(N) \leq 0 \quad q^i \geq 0 \;\; \text{and} \;\; q^i \cdot (\nabla V^i - \lambda(N)) = 0 \tag{4a}$$

$$\frac{\partial \Im}{\partial \lambda} = \sum_i y^i - \sum_i q^i \geq 0 \quad \lambda(N) \geq 0 \;\; \text{and} \;\; \lambda(N) \cdot \left(\sum_i y^i - \sum_i q^i\right) = 0 \tag{4b}$$

where $=V^i$ is the vector (of dimension t) of partial derivatives of $V^i(\bullet)$, and λ denotes the vector of Lagrange multipliers in the optimum.

Furthermore, from the former optimization problem, we can derive the following minimization problem:

$$\text{Min}\left(\lambda \cdot \sum_i y^i\right) \;\text{with respect to}\; \lambda \geq 0, \;\text{subject to}\; \left\{\nabla V^i - \lambda \leq 0\right\}_{i=1}^{n} \tag{5}$$

In the minimization problem, it must be noticed that there are n vectors of constraints, one vector for each individual.

The Lagrangian for the minimization problem is defined as follows:

$$D = \lambda \cdot \sum_i y^i + \sum_i q^i \cdot \left(\nabla V^i - \lambda\right) \tag{6}$$

The Kuhn-Tucker conditions will be:

$$\frac{\partial D}{\partial \lambda} = \sum_i y^i - \sum_i q^i \geq 0, \quad \lambda \geq 0 \;\; \text{and} \;\; \lambda \cdot \left(\sum_i y^i - \sum_i q^i\right) = 0 \tag{6a}$$

$$\frac{\partial D}{\partial q^i} = \nabla V^i - \lambda \leq 0, \quad q^i \geq 0 \;\; \text{and} \;\; q^i \cdot \left(\nabla V^i - \lambda\right) = 0, \tag{6b}$$

where q^i denotes the vector of Lagrange multipliers associated with agent i for this minimization problem.

We can verify the relationship that arises between the former optimization problems. The Lagrangian for the minimization problem can be expressed as follows:

$$\boldsymbol{D} = \lambda \cdot \sum_i \boldsymbol{y}^i + \sum_i \boldsymbol{q}^i \cdot \left(\nabla \boldsymbol{V}^i - \lambda\right) =$$

$$\lambda \cdot \sum_i \boldsymbol{y}^i + \sum_i \boldsymbol{q}^i \cdot \nabla \boldsymbol{V}^i - \sum_i \boldsymbol{q}^i \cdot \lambda + \sum_i \boldsymbol{V}^i\left(\boldsymbol{q}^i\right) - \sum_i \boldsymbol{V}^i\left(\boldsymbol{q}^i\right) =$$

$$\sum_i \boldsymbol{V}^i\left(\boldsymbol{q}^i\right) + \lambda \cdot \left(\sum_i \boldsymbol{y}^i - \sum_i \boldsymbol{q}^i\right) + \left[\sum_i \boldsymbol{q}^i \cdot \nabla \boldsymbol{V}^i - \sum_i \boldsymbol{V}^i\left(\boldsymbol{q}^i\right)\right]$$

Considering the Lagrangian of the maximization problem in equation (4), we can simplify the expression of the Lagrangian for the minimization problem:

$$\boldsymbol{D} = \Im + \sum_i \left[\boldsymbol{q}^i \cdot \nabla \boldsymbol{V}^i - \boldsymbol{V}^i\left(\boldsymbol{q}^i\right)\right] \tag{7}$$

Two points should be noticed in this equation, regarding the relationship among the optimal solutions to problems (3) and (5). Due to the concavity of the valuation function, we have:

$$\boldsymbol{q}^i \cdot \nabla \boldsymbol{V}^i \leq \boldsymbol{V}^i(\boldsymbol{q}^i)$$

Hence the following condition for the Lagrangian functions of the two optimization problems will be binding;

$$\boldsymbol{D} \leq \Im \ \ \textbf{or} \ \ \lambda \cdot \sum_i \boldsymbol{y}^i + \sum_i \boldsymbol{q}^i \cdot \left(\nabla \boldsymbol{V}^i - \lambda\right) \leq \sum_{i=1}^{n} \boldsymbol{V}^i\left(\boldsymbol{q}^i\right) + \lambda \cdot \left(\sum_i \boldsymbol{y}^i - \sum_i \boldsymbol{q}^i\right)$$

Furthermore, due to the complementary slackness condition in (4b) and (6b), the second term in both sides of the inequality cancel out, leading to the following relationship between the solutions of problems (3) and (5):

$$\textbf{Min}\ \lambda \cdot \sum_i \boldsymbol{y}^i \leq \textbf{Max} \sum_{i=1}^{n} \boldsymbol{V}^i\left(\boldsymbol{q}^i\right)$$

The inequality says that the value of the capacity of the common facility does not exceed the maximal total valuation of its services. The existence of that gap allows an opportunity for an arrangement among the users of the pipeline through a market for capacity. The existence of the vector of shadow prices λ, derived in the maximization problem, provides a powerful instrument for reaching an arrangement that optimizes the use of capacity of the public facility among the consumers. Thus agents will be able to improve their situations by

trading their rights of property to the pipeline, selling excess or buying additional capacity in such a way that the capacity of the common facility will be allocated optimally.

The rate system defined by the optimization problem equilibrates the market for capacity, creating the signals that allow the different economic agents to take adequate economic decisions. Furthermore, it provides the industry with a device for finding the opportunity cost of capacity at any specific time.

Thus, the acquisition of capacity rights is susceptible to competition, and a free market for capacity allows the agents concerned to trade their rights and find the optimal use of the pipeline. The equilibrium between demand and supply sets the charge for capacity equal to its shadow price at each period in such a way that, if each agent pays the shadow price of capacity of the common facility, social welfare will be maximized and the market will efficiently allocate the capacity of the common facility users.

Peak load pricing

An important factor derived from the previous analysis is the existence of prices for different time slots depending on agents' valuations. In particular, we notice that the shadow price of capacity gives us a peak-load pricing scheme.

Suppose there is one time slot j with excess capacity. Then the following inequality will be binding:

$$\sum_{i=1}^{n} q_j^i \leq \sum_{i=1}^{n} y_j^i$$

Therefore, due to the complementary slackness condition in (4b), the shadow price associated with that time slot will be zero. Thus, whenever there is excess capacity during a time slot, the price for capacity in that period of time will be zero, while whenever capacity is fully used, there is a positive price for that capacity.

The result above is an important element to be considered in designing pricing policies for industries with capacity restrictions over time. Due to the variability of demand for a public facility, most of times will be easy to identify two consumption periods, one in which capacity is binding (peak periods) and one with excess capacity (off-peak periods). Hence the associated shadow price of capacity in the peak period will be positive, while the shadow price associated with periods with excess capacity will be zero, making the peak users bear the whole cost of capacity since they are responsible for it. Thus the charges to peak-period users will allocate the costs of capacity improvements efficiently, and will send strong signals about the demand for extra capacity.[4]

Cost and Benefits of a Market for Capacity in Natural Gas Transportation Industries

Creating a market for capacity can be expected to provide benefits. However, those benefits are likely to have different impacts among the various segments of users and to have associated and sometimes offsetting costs.

Certainly, some problems have to be faced in order to make competitive markets work in the natural gas transportation industry. The centerpiece of the capacity market is the ability to introduce transportation competition. Thus, the question is how effectively a viable free market can be sustained over the long term, when such competition must take place, even though pipeline systems may be operated as local monopolies.

To create competition, the government and the regulatory authorities must create the proper conditions. Attempts to introduce competition in a structure as the one of the natural gas transportation industry should promote the creation of property rights for the capacity.

Once property rights are introduced in the industry, a condition for the proper functioning of a market for capacity is access to nondiscriminatory information. Complete and timely information about available transportation capacity and transactions will provide a powerful instrument for those who buy and sell that capacity, and will allocate its use to those who most value it. Alternatively, it must be allowed the existence of brokers to promote the trade of capacity of the transportation system.[5] Those brokers will match up buyers with sellers of

[4] Off-peak users are not responsible for the creation of additional capacity, hence they should not bear its cost. However, this does not exclude them from paying the variable cost of moving the natural gas throughout the pipeline.

[5] Operation of secondary markets may be promoted by the industry brokers. The information created by these brokers will provide flexibility to the long-term contracts; furthermore, such flexibility will reduce moral hazard problems as long as reputation is acquired through the transactions among the agents.

capacity, taking a buyer-reseller role. Under these circumstances, using a broker's service could be less costly for a consumer than expending resources on staff and equipment in order to arrange its own gas purchases.

The capacity market will help to ensure that pipeline capacity is held by those who value it most. If prices for capacity are allowed to move freely, the owners of property rights will be able to sell unneeded capacity at a price determined by the market, allowing them to negotiate an assignment of capacity that reflects the services that they need from the pipeline company. Such an arrangement would prove particularly beneficial to large industrial users and electric utilities. Since these users will be able to modify their capacity responsibilities according to their necessities, the arrangement will have an appreciable effect on costs. In addition, any reduction of costs to industrial users and power generation companies could be of indirect value to their consumers, since it might in turn reduce the price of the products or services it provides.

Flexible prices for capacity may also increase efficiency by promoting use of the pipeline more evenly throughout the year. The greater potential for price flexibility offered by a capacity market will increase the flexibility with which economic agents are able to adjust to market conditions, thereby allowing an efficient use of the pipeline capacity and promoting high load factors in the system.

Market prices will allow transportation companies to take advantage of economies of scale by designing pipelines that minimize operation and capital costs. This will generate investments at an adequate level to face market demands. If transportation rates were low, additional pipeline capacity would have to be constructed until the market rate fell in order to eliminate any economic rent. On the other hand, if rates were overpriced, the resulting excess capacity would keep potential investors out of the market.

Conclusions

Throughout this paper, particular emphasis is placed on the role of long-term contracts to efficiently allocate the risks of an investment of the nature of a pipeline. Due to the inherent risk of every economic transaction in the natural gas transportation industry, long-term contracts may guarantee the financial viability of an investment of the nature of a pipeline with immobile and specialized capital. Another factor of relevance to the pricing policies of this industry is the creation of a market that would be required to have a dynamic and efficient allocation of capacity over time.

The model proposed attempts to simulate the behavior of agents who use a common facility during different periods of time, given that the capacity of the facility is constrained. The approach of the model is to find optimal pricing so that the common facility is used efficiently. It has been shown that if individuals have property rights to the capacity of the common facility, the result of the analysis leads to the existence of market-clearing prices for the capacity of the pipeline at different periods of time. Moreover, a peak-load pricing scheme was obtained, in which, whenever there is excess capacity during a time slot, the price for the capacity in that period of time will be zero, whereas whenever the capacity is fully used, there is a positive price for that capacity.

Finally, it must be noted that the results proposed for the natural gas industry in the paper may be adapted to many other industries that have scale economies and specific capital. First, the common cost allocation described in this paper may be suitable to apply in industries such as railroads, electric power generation and transmission, telecommunication industries, and oil pipelines, among others. By applying the results obtained in the analysis above, these industries would be able to break-even and to produce according to cost-minimizing principles. Second, the market-for-capacity framework may be applied to facilities with a capacity constraint, such as the oil and electricity transmission industries. Here, benefits of that approach are similar to those described for the natural gas industry: efficient allocation of capacity over time and the existence of an accurate mechanism for revealing the signals that guide the investing and consumption decisions of the agents in these industries.

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