ANALYSIS OF OPTIMAL TARIFF SCHEDULES IN GAS TRANSPORTATION UNDER OPEN ACCESS

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ABSTRACT

This document analyses the effects of regulation and competition policy on the structure of the gas market. The natural monopoly features of transportation, added to the physical and technological features of gas as a commodity, allow this activity to be the focus of interesting regulatory procedures directed to increase the level of competition in the wholesale trading and supply segment. We will focus on the mandatory open access regime, and employ the most relevant analytical frameworks including the Ramsey Pricing structure and the Efficient Component Pricing Rule (ECPR). While presenting these schemes, we try to introduce the principles of nonlinear pricing (second-degree price discrimination) to take advantage of customer's heterogeneity in different dimensions as duration or reliability of the contracts. As is traditional in studies related to access pricing, we show that under specific conditions the ECPR yields the same results of a Ramsey structure.

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JEL classification: D4, L95, L51

INTRODUCTION

The objective of this document is first to analyze from a general point of view the structure of the gas market. After getting some ideas about that, we will analyze the effects that the regulation and competition policy, developed in the last years, have had on the composition of this sector.

Once we show that the regulatory environment generates the separation or unbundling of the market in (i) a natural gas market (encompassing both physical and financial markets), and (ii) a gas transportation market; we will develop a detailed description of the latter, given its economic and technical relevance. This means that the natural monopoly features of the transportation activity, added to the physical and technological properties of gas as a commodity; allow this activity to be the

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focus of interesting regulatory procedures. This regulation activity is intended to increase the level of competition in the wholesale trading and supply segment which is contemplated as a potentially competitive one. This section of the market employs as an "essential input" the transportation services administered by a gas utility which corresponds to a vertically integrated monopolist that not only is responsible for transportation of gas along high-pressure pipelines, but also is a participant in the wholesale trading activities.

To accomplish this objective, the regulator may impose an open access regime which can be negotiated or mandated. We will focus on the mandatory open access, which makes the regulator responsible of designing publicly known price lists for the access charges. Regarding to this, we try to follow the most relevant frameworks up to these days about access pricing. One of them, corresponds to the Ramsey Pricing structure, developed by Laffont and Tirole (1994, 1998, 2000). The other one is called the Efficient Component Pricing Rule "ECPR" initially proposed by Baumol (1983) and Baumol and Sidak (1994, Ch. 7), but compared to the first by Armstrong, Doyle and Vickers (1996). Both of them correspond to a linear framework that accomplish the principles of third-degree price discrimination, where the pricing rules are designed to satisfy a second-best condition motivated by the breakeven constrain of the gas utility.

While presenting these schemes, we try to introduce the principles of nonlinear pricing (second-degree price discrimination) to take advantage of customer's heterogeneity in different dimensions as duration or reliability of the contracts. We will focus on the last dimension because it has been considered one of the most relevant by different authors as Wilson (1989) and Lawrey (1998). Finally, as it is traditional in the works related of access pricing, we show that under specific conditions the ECPR yields the same results of a Ramsey structure.

I. GENERAL STRUCTURE OF THE GAS INDUSTRY

Following the analysis of the gas sector developed by Juris (1996), the natural gas industry is an economic activity composed by the following segments: production, pipeline transportation, trading and supply, and distribution. Natural gas production consists of the large set of operations necessary to deliver natural gas to the wellhead, such as exploration, drilling, production, and gathering[1]. Production is characterized by multiproduct scale economies across the whole set of operations at the firm level, but these scale economies typically are not large enough to eliminate competition at the industry level. Moreover, producers must incur substantial fixed start-up costs, much of them sunk; first in the acquisition of drilling rights and technology and then in exploration and drilling. Accordingly, the optimal size of a production firm is large because it is more feasible for it to perform both exploration and drilling than to

1 Gathering is the aggregation of natural gas produced by individual wellheads and its delivery to a location such as a terminal, where it is injected into a pipeline. It is usually considered part of the production, because producers often own and operate gathering pipelines.

separate these tasks because of the uncertainty in searching for natural gas. Nevertheless, the size of a production firm is normally small relative to the dimension of the natural gas market.

Natural gas transportation is the set of operations to deliver natural gas from a producer to wholesale markets through high-pressure pipelines[2]. It comprises the pipelines of high pressure and the storage installations with the purpose of stocking reserves until the level of distribution. The transportation segment is considered as the most important one, because of the physical properties of gas; represented by the fact that one cubic meter of natural gas under a normal pressure contains 10-6 less energy than oil. In addition to this, transportation costs of gas are ten times higher than oil ones (measured as cost per unit of energy).

This component of the market is characterized by natural monopoly because of the large multiproduct economies of scale resulting from the substantial participation of fixed and sunk costs over the total cost. Pipeline capital costs include the cost of the pipe and the cost of compressors needed to push the gas through the pipe[3]. Moreover, economies of scale are also determined by technical properties of the gas transportation activities; for example, according to Lawrey (1998), pipeline capacity[4] is proportional to the diameter of the pipe raised to the power of 2.5 rather than the power of 2 due to the greater ease of flow through pipelines as diameter is increased. Contrary to this, operating expenses are relatively low, because it costs little to move natural gas through pipelines.

There are also economies of scale associated with the multiproduct characteristics of transportation services. A pipeline company can use the same pipeline system to offer a range of services covering storage and a variety of transportation services that differ in time, location, calorific value of natural gas, intake and offtake pressure of the pipeline, and reliability. The latter dimension, is considered the most relevant of all , and will be considered in detail in this document. When we add together all these facts, we get that only one pipeline company can typically operate in the transportation segment, although we have to mention that in the future, large markets can accommodate several pipeline companies[5].

Trading and supply activities, correspond to the resale of natural gas in the wholesale market, and in the retail market, respectively. Because these two operations are closely related, they are often performed by the same firm. The gas trading and

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2 The normal dimensions of a high-pressure pipeline are: Diameter 600 to 1400 mm and pressure 40 to 80 bars.

3 As pressure decreases with distance, it is necessary to install compression plants, but their capital costs increase at a rate less than the increase in the pressure ratio they bring about (IEA (1994)).

4 The capacity of a pipeline is determined by the pressure differential between its extremities and by its diameter. An increase in diameter implies an increase of the capacity in more than a proportional way.

5 The scope for competition between pipelines depend not only on the economies of scale, and the geographic location of producers and consumers, but also on the demand level. As a rule, however, given the substantial economies of scale in transmission pipelines, it is not possible at all in the short and medium term to speak about inter-pipeline competition.

supply business is a very competitive segment because of the limited scale economies (its participants need little direct investment to start operations). This fact determines that the optimal size of a gas trader or supplier be small relative to the gas market.

Finally, natural gas distribution involves the operations required to deliver natural gas to the end users, including low-pressure pipeline transportation, supply of natural gas, metering, and construction of customer sites. Distribution is characterized by natural monopoly because of economies of scale in transportation operations. Additionally, there are economies of scope among various operations of a distribution company, because they are performed by the same distribution pipeline system. It is still unclear whether the economies of scope are large enough to prevent efficient unbundling of transportation and supply operations at the distribution level[6].

II. "OPEN ACCESS" AND MARKET PERFORMANCE

The regulatory reform in the gas sector has tried to introduce competition in the segments where it is possible to do so (See IEA (1998)). The viability of competition in the natural gas industry, as in any other economic activity, is determined by three factors: technology, the size of the market, and entry barriers. After having exposed the structure of the market in section 1, it results comprehensible that the regulatory activity and specifically its competition policies try to induce entry in the production and wholesale trading segments.

However, to accomplish this goal, the regulatory agency should design adequate measures to minimize the distortions of the related noncompetitive segments. With respect to the trading and supply segment, the entrants need access to the pipeline transportation services considered as an essential facility. This fact makes it crucial in the regulatory activity, to optimally design the access charges to the pipeline's operator services. Additionally, there are two important actors in the regulation of the transportation segment: the pipeline operator and the storage operator. Sometimes they can be integrated in the same gas utility (as in most of the European countries), but deregulation measures are trying to introduce some "unbundling" of these two activities in order to moderate the monopoly power distortions on the pricing rules.

The establishment of a market structure with competing suppliers and consumers who have the right to exercise choice encourage suppliers systematically to seek out productivity gains and comparative advantages. This is a self-reinforcing process. As new market entrants appear, they disturb the rules of the game and generate new competitive pressures and commercial initiatives. The drive for economic efficiency leads inevitably to a radical reorganization of market and industry structure.

In the new market structure created by the "Open Access" regime, a gas utility offers two kinds of services: supplying natural gas to final consumers and making

6 Distribution companies typically enjoy exclusivity in natural gas supply in their region, but an increasing number of countries have instituted open access in this segment.

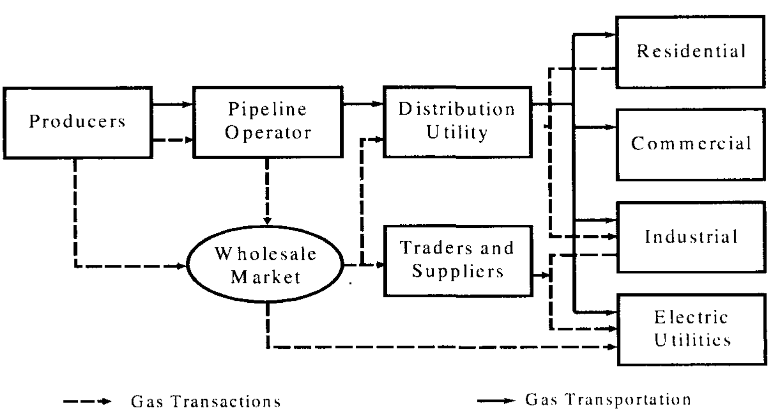
available transportation services to large end users and other eligible industry participants that purchase natural gas independently in the wholesale market. These two different kinds of services engender their respective markets: the natural gas market, which facilitates the trading of gas as a commodity, and the transportation market, which enables market participants to trade the transportation services necessary to ship natural gas through the pipeline system (*See* Figure 1).

Once it has been put in practice, the open access policy promotes efficiency in the wholesale gas market and benefits all its participants. Producers gain because this guiding principle significantly increases the number of buyers, eliminating the monopsony problem of a vertically integrated monopoly. Like so, downstream industry participants, such as distribution utilities or large end users, take advantage of direct access to the production segment and a greater choice in gas supply.

Even though the open access policy implies gains to almost everybody, its implementation generates new tasks, as the rigorous coordination of proper and third-party natural gas transportation from side to side of the pipeline network (rationing mechanisms) that will have direct and indirect effects over the structure of the access charges. Additionally, the building of this dynamic environment requires three fundamental regulatory tasks: (i) protect end users from the monopoly power of gas utilities, (ii) promote competition in the wholesale gas market, and (iii) restrict the market power of pipeline companies relative to the users of their pipeline networks.

Under mandatory access, the regulator takes responsibility for the level of access prices and for the extension of competition to the entire market. As we will see further, price caps on access and on the final prices in the wholesale market have become important instruments in carrying out this task. Now, owing to the relevance of the transportation market in the regulatory activity, we will analyze comprehensively its properties in the next section.

FIGURE 1
Natural Gas Market Structure under Open Access Regime



Source: Juris (1996). The dotted lines correspond to the new feasible transactions in both the natural gas (commodity) and gas transportation (service) markets.

A. Transportation Market

A good description of this new market is given by Juris (1998a). He defines it as the place where transportation services, recognized as the combination of pipeline capacity and natural gas shipments for delivery to a desired location, are sold in the form of transportation contracts. As we mentioned before, the transportation market emerges when pipeline companies offer open access to their pipeline grids; however, it develops further with unbundling[7] and the introduction of retail competition.

The supply side of the market is composed by the national pipeline companies, and the demand side by shippers[8], local distribution companies (LDC), power generators and large end consumers; that procure pipeline capacity and transportation from the supply segment of this market. Many gas customers are captive, since they have no immediate alternative to using gas, so that overall demand may be price inelastic in the short term. Captive customers require uninterrupted supply at all times. Conversely, non-captive customers with the ability to switch fuels or plant may be supplied under interruptible contracts, allowing supplies to be diverted to captive customers at times of peak demand.

With respect to the contracts, they are sold by pipeline companies to shippers. The most common conditions specified in them relate to the size of reserved capacity, the size of natural gas shipment, the location of points of injection and withdrawal, pipeline pressure, the time and duration of service, service reliability, and charges for capacity and throughput (transportation service). This last condition, represents the tradition of designing two part tariffs in this market; where the fixed fee is intended to recover fixed costs (capacity) and the marginal price to recoup the variable cost (transportation).

1. Primary Transportation Market

The primary transportation market facilitates the initial distribution of transportation contracts. The contracts supplied by pipeline operators, give the shippers that buy them the right to transportation services under previously specified conditions. The characteristics of service determine the structure of the contracts, with the most important being duration and reliability. Duration-based transportation contracts are divided into long, medium, and short-term contracts, linking them to the duration of gas supply. However, we will not take into account this dimension in the present document.

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7 In this case, unbundling refers to the separation of natural gas supply and wholesale distribution from pipeline transportation. The fundamental reason for this policy is determined by the ability of pipeline operators to restrict competition in the wholesale gas market through non-price measures, such as offering low-quality transportation measures. A deeper explanation of this incentives to non-price discrimination can be found in Economides (1998).

8 Shippers is the technical name of a firm that buy gas from producers, sell it to suppliers and contract a public gas transporter for transportation of the gas to consumers. They are usually marketers and traders.

Alternatively, reliability-based transportation contracts can be divided into two major categories: firm and interruptible. A firm transportation contract gives its holder the right to capacity and transportation over the whole life of the contract, regardless of the season. The holder of the contract can ask for shipment of natural gas up to the maximum reserved capacity (capacity utilization is measured by the load factor, calculated as the ratio of average daily capacity usage to the maximum daily reserved capacity). Conversely, an interruptible transportation contract[9] gives its holder the right to ship a specified volume of natural gas within a certain period, for example, within a particular month. But the timing of transportation is determined by the pipeline company according to the availability of capacity.

The nature of contracting for transportation services varies with industry structure and regulation. Vertically integrated natural gas companies typically offer long-term firm transportation contracts (take-or-pay) that specify the total volume of gas to be delivered to the users over the life of the contract. Users then specify monthly or quarterly deliveries that must add up to this total contracted volume by the end of the contract.

Shippers and the other participants purchase transportation contracts in combinations that allow them to achieve the desired service reliability at the minimum cost and to take advantage of time and locational price differentials in the natural gas market[10]. The premium a holder is willing to pay for a high-reliability contract is mainly determined by the probability of congestion and the size of price differentials between two spot markets[11]. If local spot prices of natural gas are high because of congestion in the pipeline system, a shipper who possesses a firm transportation contract can buy lower-priced natural gas in a neighboring spot market and sell it in the congested local market. The shipper's ability to reduce its own cost of natural gas or earn extra profit through locational price arbitrage is reflected in the price of firm transportation services, which tends to be higher than the price of interruptible services. Additionally, the minimum acceptable service reliability for a shipper depends on many factors, such as its pattern of natural gas consumption, its ability to substitute natural gas for other fuels, and the structure of its gas contract portfolio.

2. Secondary Transportation Market

The main justification for the existence of a secondary transportation market consists on the need to facilitate simultaneous clearing of natural gas and transportation

9 In some countries, interruptible transportation is available only for transportation of more than a specified capacity per year, and it can be interrupted for up to a fixed number of days each year.

10 As this economic decision implies an important relationship between the natural gas market and the transportation market, any distortion in the price of transportation services is going to decrease the welfare level in both markets. This fact and the natural monopoly characteristics of pipeline transportation constitute a straight justification for the regulation of prices of transportation contracts.

11 Spot markets develop at the terminals of the pipeline network as a result of increasing need to balance supply and demand in the short term.

markets. This requirement arises as a result of short-term changes in supply and demand for individual customers that often lead to a situation in which some users do not utilize all their contracted pipeline capacity while others lack sufficient capacity to meet their needs. If regulation permits the existence of a secondary transportation market, holders of unused transportation contracts can resell them here. Buyers and sellers in this market come from all segments of the gas industry, although pipeline companies are typically excluded because of market power concerns.

Regulation of the secondary transportation market is not necessary if there is competition among buyers and sellers of transportation contracts. The price of a firm contract resold in this market has to reflect the short-run marginal cost of pipeline operation and the opportunity costs of capacity. The carrying out of this mechanism allows the prices of capacity and transportation services to adjust to changes in short-term supply and demand.

As we will see further, a secondary transportation market (linked to a spot market) is not the only solution for these kind of problems, and it could be the case that it is very costly to implement. On this topic, a secondary trading market requires standardizing transportation contracts across all important dimensions in order to promote efficient pricing of the contracts. It also requires other characteristics of a liquid spot market, such as a large number of buyers and sellers, large available capacity, and the concentration of trading in one or several locations.

Another way to realize this objective, could be established by the regulator through the design of a priority pricing mechanism that fully takes into account the heterogeneity among consumers concerning to reliability. In this situation, it would be necessary to proscribe the existence of a resale market so as to avoid the distortions derived from arbitrage activities. However, we will limit now to the above description of the theoretical properties of a secondary market, and further we will study in detail the priority pricing alternative.

III. GENERALITIES OF THE PRICING STRUCTURE IN THE GAS TRANSPORTATION MARKET

Once we have a general view about the market, we can start to formalize our ideas about the functioning of the transportation market in terms of the regulatory context of "Open Access". In this manner, our objective now is to explain the pricing behavior under this setting, in order to give bases to a posterior normative analysis about the optimal measures that could increase both economic and allocative efficiency in this market. All of this, has to be done taking into account the important development of this policy in other environments as energy transmission and telecommunications.

The difficulties in the analysis of an access tariff structure, appear because it has to accomplish at the same time several and incompatible objectives. The allocative efficiency criteria call for prices that reflect the marginal cost, but in the presence of economies of scale or scope this leaves aside the problem of cost recovery. The restrained availability of information also creates some troubles, since regulatory and competition authorities generally know less about cost and demand conditions, than the participants of the industry. As a consequence, firms will be trying to take advantage of these informational asymmetries which suggests that they should have some restrained discretion over their pricing schedule, represented, for example, by the arrangement of global price caps.

Additionally, this task becomes an important responsibility in a context, where pricing rules instead of being established on economic efficiency criteria, have been settled applying some accounting methods. Following Brown and Sibley (1986), this idea comes from the regulator's worrying about the breakeven constraint of the vertically integrated monopolist (gas utility); and at the same time preventing it to exercise market power. As in the next lines will be discussed, the main source of inefficiency is the arbitrary allocation of fixed costs under the average accounting cost pricing concept[12].

In line with these criteria, we will discuss first some economic issues related to the gas transportation market, and after we will present the general assumptions of the modeling configuration of the following sections. There, we will analyze the optimal access pricing policy designed by a benevolent regulator who has the widely known objective of the maximization of social welfare.

A Gas Transportation *vs.* Other Networks

Initially, it is common to relate the gas industry with other network activities so as to establish a benchmark for the analysis of the pricing behavior in this sector. Although it could be natural to say that the gas transportation activity resembles the electricity transmission one, we consider the point of view of Sharkey (1989)[13] where it is sustained that it is more relevant to make comparison between the former and the telecommunications business. Both industries are concerned with transporting commodities on a network of a great complexity. In both of them, local distribution (low pressure pipelines) is separately owned and is regulated by state authorities, while long-distance (high-pressure pipelines) transmission is considered a target of competition policy. As well, in both activities, rate structures have been designed to contain cross subsidies from industrial or business customers to residential customers or from region to region.

However, we consider that despite of the important lessons to learn from the telecommunications industry, we have to keep in mind their differences. One of them, involves the nature of the commodity carried on in the network. The role of the telecommunications network is to transfer an intangible commodity (considered

12 See Laffont and Tirole (1995) for some traditional methods of determination of access prices in telecommunications. The techniques applied to gas industry can be found in IEA (1994) and Boyer (1997). For structures related to specific countries see: Juris (1998a) for the U.K., Juris (1998b) for the U.S., and Lawrey (1998) for Australia.

13 In Nowotny Smith and Trebing (1989).

as information) on demand, for a large set of customers. The role of the pipeline network is to transport a physical commodity from a small set of producers to a wide set of consumers. Since the commodity is physical, there are some possibilities of storage (both in storage plants and in the network itself by varying the internal pressure 'line packing')[14] so that the operator is able to partially soften the peak-load constraints.

The most important difference, however, has to do with the market boundaries and technological change in the industry. The telecommunications industry is currently seen as one of the most dynamic in terms of research and development, which makes difficult to draw a line of separation between the transmission information and the enhancement of information. On the opposite, the transmission of natural gas is an easily defined activity with few close substitutes (the most relevant is the liquefied natural gas which in some circumstances could result more profitable in extremely long distances). Additionally, technological change in the pipeline industry is considered to follow predictable lines, in the sense that the development of a entirely new technology that replace the current one is almost impossible.

B. Applied Pricing Rules

Traditionally, in the gas transportation market, the regulator determines tariffs for firm and interruptible transportation services using the straight fixed variable rate-making method. This is a cost-based price mechanism that uses the average accounting cost pricing concept. In this context, charges for firm services are divided into a demand charge, which recovers most of the fixed costs of transportation, and a usage charge, which recovers variable (or operational) costs. The demand charge is related to the maximum daily capacity reserved by users, but the greater the reserved capacity, the lower the unit charge.

Charges for interruptible services range between maximum and minimum charges. The maximum interruptible charge recovers variable costs and a portion of fixed costs, while the minimum one recoups variable costs only. Fixed costs are allocated between firm and interruptible services on the basis of the ratio of firm to interruptible service loads in the pipeline. The firm load is equal to the total capacity reserved by firm users.

From a theoretical point of view, these pricing rules corresponds to a system of two part tariffs (*See* Lawrey (1998)). However there are problems with this structure as the fact that the entry fee can deter customers from participating in the market. The solution for this problem would be to design an additional markup on the entry fee to exercise discrimination based on contractor's elasticity of participation in the transportation market, but it is ignored in the present document.

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14 This also constitutes a difference of the gas industry with respect to electricity transmission because in the latter, there are only opportunities of storage as potential energy.

C. General Assumptions

Now, we are in position to set the fundamental hypothesis that will be considered in the different models that we will develop in the subsequent sections. First, we should state that the good subject to transactions is defined as the transportation service to ship natural gas through the pipeline. It comprises the concept of pipeline capacity and the natural gas shipments. As was emphasized above, the price of the first component has to recover the fixed costs, while the pricing rule for the latter has to be directly associated with the variable costs. On the topic of the price/cost relationship, we identify the short run marginal cost of the natural gas pipelines as the additional operating costs associated to an additional unit of throughput without altering the overall capacity. Conversely, the long run marginal cost includes all operating costs, the cost of additional capital and the depreciation expenditures.

Moreover, the participants in the market are: (i) a vertically integrated pipeline operator[15] or incumbent firm which is present in the upstream segment as a natural monopoly, and at the same time, it or one of its affiliates is a participant of the downstream segment characterized as the wholesale gas trading and supply activity; (ii) an entrant in the downstream segment that could be considered individually or as a competitive fringe. In terms of the gas market, the latter can be identified as gas traders (shippers), local distribution companies, large end users or many other eligible industry participants that act in the wholesale market. Although gas producers also have access to the pipeline services, the are ignored in this specification.

As we have mentioned from the beginning, we analyze the access pricing problem[16], where a vertically integrated pipeline operator controls the supply of the service not only as a final product, but also as an essential input for its competitors. In this situation, there is an obvious danger that the integrated gas utility will seek to exclude competing final product suppliers by establishing high access prices that are intended to increase its competitors costs in the downstream level.

It is assumed that the access regime is such that its threshold level prevents inefficient bypass of the low-pressure pipelines by some large end users. By this, we mean that the criteria that define the concept of eligible clients[17] in this environment, is such that only allows the 'physical connection' and the implicit contracting of large end consumers that is considered socially efficient. Though, this kind of bypass will not be taken into account here because it is associated with the regulatory activity in the retail distribution segment (ignored in the present document).

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15 Here we have to mention that this transportation segment could include the storage infrastructure or not. As will be seen below, this fact constitutes the possibility of increased efficiency gains in the price designing task.

16 Armstrong y Vickers (1998) states, '...the "network access pricing problem" is perhaps the most controversial of all pricing structure subjects in regulated industries.'

17 Eligible Clients are those who can sign transportation contracts in order to get some amount of natural gas. Following the 1998 European Directive about Gas Market, it must be the case that by August of 2000 be eligible the final consumers of 25 millions m^3 or more, of 15 millions m^3 or more by the same month of 2003 and 5 millions m^3 or more by 2008.

It is obvious that in this kind of industry we have to manage the problem of seasonallity but until we do not elaborate a specific setting to cover this feature, we will make the simplifying assumption that the storage infrastructure (storage plants and variations of internal pressure), the efficient and the competitive rationing method implemented in the market, and the tradition of building pipelines in order to respond to the maximal feasible demand; are so well settled that allow the integrated monopolist to continuously satisfy the demand requirements.

Furthermore, about the technological characteristics, both in the upstream (transportation activity) and downstream (wholesale distribution) sector, there is a fixed proportion technology (carriage), where for each unit of gas transported it is necessary one unit of capacity. This condition is going to play a vital role in making straightforward some calculations of the model.

On the other hand, from Armstrong, Doyle and Vickers (1996) we will assume the different ways to determine access prices for gas transportation services are restricted to: (i) Arrangement of access terms by the regulator, and (ii) the regulator allowing the firm to choose from a menu of regulatory schemes[18]. The other condition to obtain efficient access prices requires the accounting separation of transportation and wholesale activities of the integrated pipeline operator (*See* David and Mirabel (1998) for more details about the justification of this two necessary conditions).

With respect to the initial conditions, the characteristics of production and transportation investments have made that gas transactions be determined by take or pay contracts[19]. This way of doing business introduces to the market enormous rigidities, which are softened by the introduction of short and middle-term contracts. This typology of contracts is implicit in the open access regime. The transition period implied by this change generates the presence of stranded costs[20]. This kind of costs will be ignored in this document, but has to be taken into account for any type of normative analysis of the social suitability of a price structure to be implemented.

In the present analysis, we also exclude the need of regulated prices of access to reflect the costs of providing non-commercial service obligations. To solve this problem, we assume the presence of universal service funds that are in charge of financing this requirements without distorting prices.

Finally, even though legislation in most of the countries determines that transportation, distribution and storage companies cannot discriminate the network

18 This is consistent with OECD (2000) recommendations for regulation of the gas industry. They sustain that whatever approach is chosen to regulate this industry, its prices must be settled by the regulatory agency. Therefore, the question arises as to the appropriate structure of regulated prices.

19 Take or pay contracts are long term contracts (ten or more years) where the producer assures an available amount of gas to an operator and the latter has the obligation to pay, no matters if he uses it or not. In this kind of contracts prices are indexed taking as a base the liquid hidrocarbures prices.

20 Stranded costs are a form of sunk costs which cannot be recovered due to a change in the regulatory regime.

users, we will keep aside of this reality and assume that it is feasible to discriminate between consumers of gas both as a final good and as an input.

IV. MODEL 1: RAMSEY BENCHMARK IN SINGLE PRODUCT CASE

In this model we take advantage of the background developed by Laffont and Tirole (1994) and Laffont, Rey and Tirole (1998). In these two papers they build a pricing structure that takes account of the monopoly power of the incumbent and the lack of information of the regulator about productivity and demand parameters. As it was mentioned before, we start under the assumption of accounting separation in the gas utility activities in the upstream and downstream level. This to avoid the problem of cross subsidization that generates large distortions in the regulatory process.

We focus initially on the incentives of the network's monopolist to provide access. As we said before, there is a benevolent regulator whose objective corresponds to the maximization of social welfare, understood as the unweighted aggregation of the net consumers' surplus, the utility of the incumbent and the profits of the entrants. Concerning to this aggregation, it is also assumed a social cost for public funds (deadweight loss) financed by the consumers and employed to reimburse the costs incurred by the gas utility.

Initially, as we take as read the separability of the total cost function of the gas utility, we can define:

$$C_I = C_N + C_S \tag{1}$$

where C_I corresponds to the total cost in both the upstream and the downstream level, C_N in the cost of operating the network (fixed and variable costs), and C_S covers the expenditures related to offering the final good in the wholesale market. Corresponding to the network cost function, we have that

$$C_N = C_N(\beta, e_N, q_I) \quad \text{when there is no open access policy and} \tag{2a}$$

$$C_N = C_N(\beta, e_N, q_I + q_E) \text{ with open access policy, and } q_E \text{ correspond to the amount of access provided to the entrant} \tag{2b}$$

β is an adverse selection parameter related to the productivity of the monopolist in administering the network and constitutes private information of the monopolist. Despite the fact of this informational lack, the distribution function $F(\beta)$ of this parameter over the interval $(\underline{\beta}, \bar{\beta})$ is common knowledge. Additionally, the classical monotone hazard rate assumption $d\left[\frac{F(\beta)}{f(\beta)}\right]\Big/ d\beta \geq 0$ is satisfied.

On the other hand, in the current model we have a double informational lack because there also exists a reduction cost parameter of the monopolist that is part of his set of private information. This parameter can be associated to the responsibility of the pipeline operator to optimize gas flows and minimize imbalances between gas intake and offtake. This reflects a discretionary power of the gas utility over the possibilities of cost reduction in the short and medium-term. However, this objective brings about a disutility in both the upstream and the downstream levels; represented by $\psi(e_I)=\psi(e_N,e_S)$ with $\psi'>0, \psi''>0$ and $\psi'''\geq 0$ (increasing and convex function)

When we exploit the assumption of fixed proportions (carriage) technology for both participants of the gas market. This implies one unit of transportation generates one unit of gas offered to the wholesale market. Therefore, in terms of the access policy, we have $q_A \equiv q_E$, where q_A is the entrant's demand of access and q_E is the access supplied by the incumbent

Concerning to the entrants, they produce an imperfectly substitute to the gas offered by the incumbent in the wholesale market[21]. The technology is also characterized by constant returns to scale with a marginal cost c_E that is publicly known by both the monopolist and the regulator. These notions make straightforward the definition of their profit function

$$\Pi_E = p_E q_E - c_E q_E - a q_E$$

With respect to consumer's behavior, as the transportation of gas is associated to an input market, the only goods that are included in the gross surplus functions are the unit of gas obtainable in the wholesale market: q_E from the gas utility (incumbent) and q_E from the entrants. In this environment, we will work with the traditional aggregate gross surplus function $V=V(q_I,q_E)$ which is separable between both kinds of gas offered in the wholesale market. Its properties are:

$$\begin{aligned}
&\frac{\partial V(q_I(p_I,p_E),q_E(p_I,p_E))}{\partial q_I}=p_I && \frac{\partial V(q_I(p_I,p_E),q_E(p_I,p_E))}{\partial q_E}=p_E \\
&\frac{\partial V(q_I(p_I,p_E),q_E(p_I,p_E))}{\partial p_I}=p_I x_I'(p_I,p_E) && \frac{\partial V(q_I(p_I,p_E),q_E(p_I,p_E))}{\partial p_E}=p_E x_E'(p_I,p_E) \\
&\frac{\partial(V(\bullet)-T_I(q_I)-T_E(q_E))}{\partial p_I}=-x_I(p_I,p_E) && \frac{\partial(V(\bullet)-T_I(q_I)-T_E(q_E))}{\partial p_E}=-x_E(p_I,p_E)
\end{aligned} \qquad (3)$$

where $x_I(p_I,p_E)$ and $x_E(p_I,p_E)$ represent the demand functions met by the incumbent and the entrants. Finally, we consider at first that the gas delivered in the wholesale market is an homogeneous product, even tough we have mentioned that it is widely differentiated. In section V we will relax this assumption

21 This assumption also justify the presence of several firms in the competitive segment.

A. Symmetric Information Case

Here we take for granted that the benevolent regulator observes prices, quantities, the cost function, the productivity and the cost reduction parameters. Additionally, it is suitable the accounting assumption that the regulator reimburses the cost to the incumbent and at the same time receives the entire amount of wholesale and trading revenues. Conversely, the firm receives the access charges. After this, we can represent the components of the welfare function as

Pipeline's Operator Utility Level $U_I = t - \psi(e_N, e_S) + aq_E$ (4)

Consumer's Utility Level $U_C = V(q_I, q_E) - p_I q_I - p_E q_E - (1+\lambda)[t + C_I - p_I q_I]$ (5)

Entrants' Utility Level $\Pi_E = p_E q_E - c_E q_E - aq_E$ (6)

Where p_I corresponds to the price of delivered gas by the subsidiary of the monopolist in the downstream sector; and p_E is the price offered by the entrants. Placing all of this together means that the social planer maximization program is

$$\begin{aligned} \text{Max} \quad & W = U_C + U_I + \Pi_E \\ \text{s.t.} \quad & U_I \geq 0 \\ & \Pi_E \geq 0 \end{aligned} \qquad (7)$$

When both restrictions are binding, the optimization program becomes

$$\max_{p_I, p_E, e_N, e_S} W = V(q_I(p_I, p_E), q_E(p_I, p_E)) + \lambda[p_I q_I(p_I, p_E) + p_E q_E(p_I, p_E)] -$$
$$(1+\lambda)[\psi(e_N, e_S) + C_N(\beta, e_N, q_I(p_I, p_E) + q_E(p_I, p_E)) + C_S(\beta, e_S, q_I(p_I, p_E)) + c_E q_E(p_I, p_E)]$$

First, we solve the system $\begin{cases} \dfrac{\partial W}{\partial p_I} = 0 \\ \dfrac{\partial W}{\partial p_E} = 0 \end{cases}$ and it gives the following result

$$(1+\lambda)\begin{bmatrix} \dfrac{\partial q_I}{\partial p_I} & \dfrac{\partial q_E}{\partial p_I} \\ \dfrac{\partial q_I}{\partial p_E} & \dfrac{\partial q_E}{\partial p_E} \end{bmatrix} \begin{bmatrix} p_I - C_{NQ} - C_{Sq_I} \\ p_E - C_{NQ} - c_E \end{bmatrix} = -\lambda \begin{bmatrix} q_I \\ q_E \end{bmatrix}$$

([22]) and applying Cramer's Rule we obtain

22 C_{NQ} corresponds to the total marginal cost of transportation of gas along the pipeline, and C_{Sq_I} is the marginal cost incurred by the pipeline operator or its affiliate in providing gas to the wholesale market.

$$\frac{p_I - C_{NQ} - C_{Sq_I}}{p_I} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I}\left(\frac{\eta_I\eta_E + \eta_I\eta_{IE}}{\eta_I\eta_E - \eta_{IE}\eta_{EI}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I} \tag{8}$$

$$\frac{p_E - C_{NQ} - c_E}{p_E} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_E}\left(\frac{\eta_I\eta_E + \eta_E\eta_{EI}}{\eta_I\eta_E - \eta_{IE}\eta_{EI}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E} \tag{9}$$

where $\eta_I = -\frac{\partial q_I}{\partial p_I}\frac{p_I}{q_I}$ $\eta_E = -\frac{\partial q_E}{\partial p_E}\frac{p_E}{q_E}$ $\eta_{IE} = \frac{\partial q_I}{\partial p_E}\frac{p_E}{q_I}$ $\eta_{EI} = \frac{\partial q_E}{\partial p_I}\frac{p_I}{q_E}$ and $\hat{\eta}_I < \eta_I$ and $\hat{\eta}_E < \eta_E$ as a result of the substituability assumption between the incumbent and entrants' gas (This last result is signaled by Laffont and Tirole (1995)).

Afterwards, we solve the system $\begin{cases} \frac{\partial W}{\partial e_N} = 0 \\ \frac{\partial W}{\partial e_S} = 0 \end{cases}$ which yields as an outcome the condition

$$\psi'(e_N, e_S) = -\frac{\partial C_N}{\partial e_N} = -\frac{\partial C_S}{\partial e_S} \tag{10}$$

The result obtained in (10) express that the cost reimbursement rule is such that the marginal disutility of effort equals the marginal cost reduction in both the network and the wholesale distribution cost functions. To conclude, as we are interested in obtaining the price for access, we use the assumption of constant returns to scale for the entrants, or in other words, that they set prices equal to the marginal cost

$$a = p_E - c_E, \quad \text{then} \quad a = C_{NQ} + \frac{\lambda}{1+\lambda}\frac{p_E}{\hat{\eta}_E} \tag{11}$$

This implies the access charge has to be not only cost-based, but also demand-based. The last feature implies that the price of access should reflect the interactions of demand in the downstream sector. Given that there is substituability between the services offered by the subsidiary of the gas utility and the entrants in this level, the access charge should be increased from the initial level (assuming independent demand). Additionally, as it is expressed in Laffont and Tirole (2000), as competitive entrants charge purely cost-based final prices, and so are unable to price discriminate; this action has to be developed through the access pricing.

B. Asymmetric Information Case

In this case, we want to analyze the way, asymmetric information affects access pricing. In order to accomplish this objective, we consider now, that the only observable variables are the separate accounting costs of the gas utility in the transportation and wholesale distribution activities. Again, following the methodology of Laffont-Tirole (1994), we denote $E_N(\beta, C_N, q_I + q_E)$ and $E_S(\beta, C_S, q_I)$ as the effort required for a gas utility of type β to provide $q_I + q_E$ units of transportation and q_I units of gas in the wholesale market at cost C_N and C_S respectively.

In this case, the application of the revelation principle allow us to consider a revelation mechanism

$$\left\{t(\tilde{\beta}), C_N(\tilde{\beta}), C_S(\tilde{\beta}), q_I(\tilde{\beta}), q_E(\tilde{\beta}), a(\tilde{\beta})\right\} \tag{12}$$

With the above assumptions, we can express the Incumbent's utility level as

$$U_I(\beta) = t(\beta) - \psi(E_N(\beta, C_N(\beta), q_I(\beta) + q_E(\beta)), E_S(\beta, C_S(\beta), q_I(\beta))) + aq_E(\beta) \tag{13}$$

Therefore, the incentive constrain of the pipeline operator can be written as

$$\dot{U}_I(\beta) = -\psi'(e_N, e_S)\left(\frac{\partial E_N}{\partial \beta} + \frac{\partial E_S}{\partial \beta}\right) \tag{14}$$

Given that $\partial E_N/\partial\beta > 0$ and $\partial E_S/\partial\beta > 0$, we know that the utility function of the monopolist is decreasing with respect to β which implies that the rationality constraint of this optimization program ends up as

$$U_I(\bar{\beta}) \geq 0 \tag{15}$$

When we introduce all this constraints to the social welfare maximization program we get,

$$\begin{aligned}
\text{Max } W = \int_{\underline{\beta}}^{\bar{\beta}} \{ & V(q_I(p_I(\beta), p_E(\beta)); q_E(p_I(\beta), p_E(\beta))) - (1+\lambda)[\psi(e_N(\beta), e_S(\beta)) \\
& + C_N(\beta, e_N(\beta), q_I(p_I(\beta), p_E(\beta)) + q_E(p_I(\beta), p_E(\beta))) + C_S(\beta, e_S(\beta), q_I(p_I(\beta), p_E(\beta))) \\
& + c_E q_E(p_I(\beta), p_E(\beta))] - \lambda U_I(\beta) + \lambda[p_E(\beta) q_E(p_I(\beta), p_E(\beta)) \\
& + p_I(\beta) q_I(p_I(\beta), p_E(\beta))]\} dF(\beta)
\end{aligned}$$

$$\begin{aligned}
\text{s.t.} \quad \dot{U}_I(\beta) = -\psi'(e_N, e_S)\Bigg(& \frac{\partial E_N}{\partial \beta}(\beta, C_N(\beta, e_N, q_I(p_I(\beta), p_E(\beta)) + q_E(p_I(\beta), p_E(\beta))), q_I(p_I(\beta), p_E(\beta)) \\
& + q_E(p_I(\beta), p_E(\beta))) + \frac{\partial E_S}{\partial \beta}(\beta, C_S(\beta, e_S, q_I(p_I(\beta), p_E(\beta))), q_I(p_I(\beta), p_E(\beta)))\Bigg)
\end{aligned}$$

$$U_I(\bar{\beta}) \geq 0$$

Where after writing the Hamiltonian, the first order conditions are given by

$$\frac{\partial H}{\partial U_I} = -\dot{\mu}(\beta) \quad \frac{\partial H}{\partial p_I} = \frac{\partial H}{\partial p_E} = 0 \quad \frac{\partial H}{\partial e_N} = \frac{\partial H}{\partial e_S} = 0$$

Regarding to the first condition, we find that $\lambda f(\beta) = \dot{\mu}(\beta)$ and given that the utility of the monopolist is decreasing in β, the transversality condition of this optimization program implies that $\mu(\underline{\beta}) = 0$; therefore

$$\int_{\underline{\beta}}^{\beta} d\mu(\beta) = \int_{\underline{\beta}}^{\beta} \lambda f(\beta) d(\beta) \quad \Rightarrow \quad \mu(\beta) = \lambda F(\beta)$$

The first order conditions with respect to both prices will deliver similar solutions to the perfect information case, but adding the distortion generated by the informational lack. Still, to obtain the above mentioned solution, it is important to clarify the following procedure. When we totally differentiate the unbundled cost function of the gas utility, we get the following expressions

$$dC_N = \frac{\partial C_N}{\partial \beta} d\beta + \frac{\partial C_N}{\partial e_N} de_N + \frac{\partial C_N}{\partial Q} dQ; \quad dC_S = \frac{\partial C_S}{\partial \beta} d\beta + \frac{\partial C_S}{\partial e_S} de_S + \frac{\partial C_S}{\partial q_I} dq_I$$

If we evaluate this total differential in the optimal levels of effort, $E_N(\beta, C_N, q_I + q_E)$ and $E_S(\beta, C_N, q_I)$, we can say that $dC_N = dQ = 0$ and $dC_S = dq_I = 0$, as an application of the Envelope Theorem.

Then, we get that $\frac{dE_N}{d\beta} = -\frac{\partial C_N}{\partial \beta} \Big/ \frac{\partial C_N}{\partial e_N}$ and $\frac{dE_S}{d\beta} = -\frac{\partial C_S}{\partial \beta} \Big/ \frac{\partial C_S}{\partial e_S}$

Once we have explained that, we solve directly the system $\begin{cases} \dfrac{\partial H}{\partial p_I} = 0 \\ \dfrac{\partial H}{\partial p_E} = 0 \end{cases}$ which gives,

$$\begin{bmatrix} \frac{\partial q_I}{\partial p_I} & \frac{\partial q_E}{\partial p_I} \\ \frac{\partial q_I}{\partial p_E} & \frac{\partial q_E}{\partial p_E} \end{bmatrix} \begin{bmatrix} (p_I - C_{NQ} - C_{Sq_I}) - \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\psi'(\bullet)\left(\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right) + \frac{\partial}{\partial q_I}\left(-\frac{\partial C_S}{\partial \beta}\Big/\frac{\partial C_S}{\partial e_S}\right)\right) \\ (p_E - C_{NQ} - c_E) - \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\psi'(\bullet)\left(\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right)\right) \end{bmatrix} = -\frac{\lambda}{1+\lambda}\begin{bmatrix} q_I \\ q_E \end{bmatrix}$$

and applying Cramer's Rule we will get

$$\frac{p_I - C_{NQ} - C_{Sq_I}}{p_I} = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I} + \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_I}\left(\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right) + \frac{\partial}{\partial q_I}\left(-\frac{\partial C_S}{\partial \beta}\Big/\frac{\partial C_S}{\partial e_S}\right)\right) \quad (16)$$

$$\frac{p_E - C_{NQ} - c_E}{p_E} = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E} + \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_E}\left(\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right)\right) \quad (17)$$

As a result, we obtain the next expression for the access charge that is very similar to equation (11) and shows that under asymmetric information. All prices are modified by the incentive correction term that is determined by the rate at which the gas utility is able to substitute decreases in effort for improvements in productivity (given the same cost level). However, if the incentive-price dichotomy assumption (*See* Laffont and Tirole (1993, Ch. 3) represented by

$$\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right)=0 \tag{19}$$

is accomplished, the incentive-correction term disappears. Then, the access charge would be the same to the one under perfect information.

Finally, we solve the system $\begin{cases}\dfrac{\partial H}{\partial e_N}=0\\ \dfrac{\partial H}{\partial e_S}=0\end{cases}$ and it gives the following result

$$\psi'(e_N(\beta), e_S(\beta)) = -\frac{\partial C_N}{\partial e_N}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\left\{\psi''(e_N(\beta), e_S(\beta))\left(\frac{\partial E_N}{\partial \beta}+\frac{\partial E_S}{\partial \beta}\right)+\psi'(e_N(\beta), e_S(\beta))\left(\frac{\partial^2 E_N}{\partial \beta \partial C_N}\frac{\partial C_N}{\partial e_N}\right)\right\} \tag{20}$$

$$\psi'(e_N(\beta), e_S(\beta)) = -\frac{\partial C_S}{\partial e_S}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\left\{\psi''(e_N(\beta), e_S(\beta))\left(\frac{\partial E_N}{\partial \beta}+\frac{\partial E_S}{\partial \beta}\right)+\psi'(e_N(\beta), e_S(\beta))\left(\frac{\partial^2 E_S}{\partial \beta \partial C_S}\frac{\partial C_S}{\partial e_S}\right)\right\} \tag{21}$$

Those two last equations represent the modified cost reimbursement rules, where for reasons of simplicity, we assume that the conditions that determine the correction term to be positive are accomplished. This expression represents the increase in the utility of all types up to β when, the latter increases effort in one unit (This term is zero for $\bar{\beta}$).

Finally, as it is shown in Laffont and Tirole (1994 and 1996), this Ramsey pricing rule can be induced in practice by the designing of a global mark up that defines symmetrically an average price level for access and final prices[23], of the form

$$\varpi_A a + \varpi_I p_I \le p$$

This possibility, also leaves aside the informational problems of Ramsey prices argued by the common criticism (*See* Laffont and Tirole (2000), and Wilson (1993)). However it is important to mention that this is not a perfect measure, because there is a possibility that the GPC leaves substantial profits to the gas utility.

23 If the weights in a linear global cap are set correctly (in function of quantities demanded for each relevant range), Ramsey pricing is induced.

V. MODEL 2: RAMSEY BENCHMARK IN MULTI-PRODUCT CASE

Up till now, we have ignored the fact that gas transportation, as all network industries, is essentially multiproduct in nature. Accepting that a pipeline company can use the same network system to offer transportation services that differ in time, location, calorific value of natural gas, intake and offtake pressure of the pipeline, and reliability; it results crucial to take advantage of this special feature. However, as was highlighted in section II, we will restrict ourselves to a single dimension, that corresponding with our objectives deals with reliability.

Along these lines, and for ease of the analysis, we assume that there are only two types of reliability, (i) firm transportation contracts, and (ii) interruptible transportation contracts. Although this simplification, we consider that it will reflect adequately the characteristics of the market. Furthermore, this attribute will be the same for the final service offered by the gas utility, the access supplied to the entrants (one or competitive fringe) and the service delivered by the latter. Thus, we have that

$\mathbf{q}_I = (q_I^F, q_I^{NF}) \quad \mathbf{q}_E = (q_E^F, q_E^{NF}) \quad \mathbf{q}_A = (q_A^F, q_A^{NF})$ will represent the vector of quantities, and

$\mathbf{p}_I = (p_I^F, p_I^{NF}) \quad \mathbf{p}_E = (p_E^F, p_E^{NF}) \quad \mathbf{a} = (a^F, a^{NF})$ relate to the vector of prices.

In this new setting, we will analyze the results in both the symmetric and asymmetric information case.

A. Symmetric Information Case: Differentiation in Reliability

Here we have that the regulator's optimization program is given by

$$\max_{\mathbf{p}_I, \mathbf{p}_E, e_N, e_S} W = V(\mathbf{q}_I(\mathbf{p}_I,\mathbf{p}_E), \mathbf{q}_E(\mathbf{p}_I,\mathbf{p}_E)) + \lambda[\mathbf{p}_I \cdot \mathbf{q}_I(\mathbf{p}_I,\mathbf{p}_E) + \mathbf{p}_E \cdot \mathbf{q}_E(\mathbf{p}_I,\mathbf{p}_E)] -$$
$$(1+\lambda)\left[\psi(e_N,e_S) + C_N(\beta, e_N, \mathbf{q}_I(\mathbf{p}_I,\mathbf{p}_E) + \mathbf{q}_E(\mathbf{p}_I,\mathbf{p}_E)) + C_S(\beta, e_S, \mathbf{q}_I(\mathbf{p}_I,\mathbf{p}_E))\right.$$
$$\left. + \mathbf{c}_E \cdot \mathbf{q}_E(\mathbf{p}_I,\mathbf{p}_E)\right]$$

First, we solve the system $\begin{cases} \dfrac{\partial W}{\partial p_I^F} = 0 & \dfrac{\partial W}{\partial p_E^F} = 0 \\ \dfrac{\partial W}{\partial p_I^{NF}} = 0 & \dfrac{\partial W}{\partial p_E^{NF}} = 0 \end{cases}$ and it gives the following result[24]

24 To clarify, the notation is the following: $Q^F = q_I^F + q_E^F \quad Q^{NF} = q_I^{NF} + q_E^{NF} \quad Q = Q^F + Q^{NF}$

$$\begin{bmatrix} \frac{\partial q_I^F}{\partial p_I^F} & \frac{\partial q_E^F}{\partial p_I^F} & \frac{\partial q_I^{NF}}{\partial p_I^F} & \frac{\partial q_E^{NF}}{\partial p_I^F} \\ \frac{\partial q_I^F}{\partial p_E^F} & \frac{\partial q_E^F}{\partial p_E^F} & \frac{\partial q_I^{NF}}{\partial p_E^F} & \frac{\partial q_E^{NF}}{\partial p_E^F} \\ \frac{\partial q_I^F}{\partial p_I^{NF}} & \frac{\partial q_E^F}{\partial p_I^{NF}} & \frac{\partial q_I^{NF}}{\partial p_I^{NF}} & \frac{\partial q_E^{NF}}{\partial p_I^{NF}} \\ \frac{\partial q_I^F}{\partial p_E^{NF}} & \frac{\partial q_I^F}{\partial p_E^{NF}} & \frac{\partial q_I^{NF}}{\partial p_E^{NF}} & \frac{\partial q_E^{NF}}{\partial p_E^{NF}} \end{bmatrix} \begin{bmatrix} p_I^F - C_{NQ^F} - C_{Sq_I^F} \\ p_E^F - C_{NQ^F} - c_E \\ p_I^{NF} - C_{NQ^{NF}} - C_{Sq_I^{NF}} \\ p_E^{NF} - C_{NQ^{NF}} - c_E \end{bmatrix} = -\frac{\lambda}{(1+\lambda)} \begin{bmatrix} q_I^F \\ q_E^F \\ q_I^{NF} \\ q_E^{NF} \end{bmatrix}$$

To simplify the solution of this system, we assume that the demand of the two types of transportation contracts is independent (this constitutes a strong assumption, because it would result interesting to analyze the effect of changing prices on firm transportation contracts on the demand for interruptible ones). This suggests that,

$$\frac{\partial q_k^F}{\partial p_j^{NF}} \equiv \frac{\partial q_k^{NF}}{\partial p_j^F} \equiv 0 \quad \forall\, k, j = E, I$$

And the system of equations boils down to

$$\begin{bmatrix} \frac{\partial q_I^F}{\partial p_I^F} & \frac{\partial q_E^F}{\partial p_I^F} & 0 & 0 \\ \frac{\partial q_I^F}{\partial p_E^F} & \frac{\partial q_E^F}{\partial p_E^F} & 0 & 0 \\ 0 & 0 & \frac{\partial q_I^{NF}}{\partial p_I^{NF}} & \frac{\partial q_E^{NF}}{\partial p_I^{NF}} \\ 0 & 0 & \frac{\partial q_I^{NF}}{\partial p_E^{NF}} & \frac{\partial q_E^{NF}}{\partial p_E^{NF}} \end{bmatrix} \begin{bmatrix} p_I^F - C_{NQ^F} - C_{Sq_I^F} \\ p_E^F - C_{NQ^F} - c_E \\ p_I^{NF} - C_{NQ^{NF}} - C_{Sq_I^{NF}} \\ p_E^{NF} - C_{NQ^{NF}} - c_E \end{bmatrix} = -\frac{\lambda}{(1+\lambda)} \begin{bmatrix} q_I^F \\ q_E^F \\ q_I^{NF} \\ q_E^{NF} \end{bmatrix}$$

The matrix of partial derivatives can be interpreted as a diagonal partitioned matrix

$$\begin{bmatrix} \frac{\partial \mathbf{q}_k^F}{\partial \mathbf{p}_j^F} & \mathbf{0} \\ \mathbf{0} & \frac{\partial \mathbf{q}_k^{NF}}{\partial \mathbf{p}_j^{NF}} \end{bmatrix} \begin{bmatrix} p_I^F - C_{NQ^F} - C_{Sq_I^F} \\ p_E^F - C_{NQ^F} - c_E \\ p_I^{NF} - C_{NQ^{NF}} - C_{Sq_I^{NF}} \\ p_E^{NF} - C_{NQ^{NF}} - c_E \end{bmatrix} = -\frac{\lambda}{(1+\lambda)} \begin{bmatrix} \mathbf{q}_k^F \\ \mathbf{q}_k^{NF} \end{bmatrix}$$

Taking into account that

$$\begin{bmatrix} \frac{\partial q_k^F}{\partial p_j^F} & 0 \\ 0 & \frac{\partial q_k^{NF}}{\partial p_j^{NF}} \end{bmatrix}^{-1} = \begin{bmatrix} \left(\frac{\partial q_k^F}{\partial p_j^F}\right)^{-1} & 0 \\ 0 & \left(\frac{\partial q_k^{NF}}{\partial p_j^{NF}}\right)^{-1} \end{bmatrix}$$

we obtain identical results to the single product case

$$\frac{p_I^\ell - C_{NQ^\ell} - C_{Sq_I^\ell}}{p_I^\ell} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I^\ell}\left(\frac{\eta_I^\ell \eta_E^\ell + \eta_I^\ell \eta_{IE}^\ell}{\eta_I^\ell \eta_E^\ell - \eta_{IE}^\ell \eta_{EI}^\ell}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^\ell} \quad \forall\, \ell = {}_{F,NF} \tag{22}$$

$$\frac{p_E^\ell - C_{NQ^\ell} - c_E}{p_E^\ell} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_E^\ell}\left(\frac{\eta_I^\ell \eta_E^\ell + \eta_E^\ell \eta_{EI}^\ell}{\eta_I^\ell \eta_E^\ell - \eta_{IE}^\ell \eta_{EI}^\ell}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E^\ell} \quad \forall\, \ell = {}_{F,NF} \tag{23}$$

Here we will take as granted that $C_{NQ^F} \geq C_{NQ^{NF}}$ which implies that serving low reliability contracts is less costly than serving firm contracts. Additionally, $\hat{\eta}_I^F \leq \hat{\eta}_I^{NF}$ and $\hat{\eta}_E^F \leq \hat{\eta}_E^{NF}$ as a consequence of the fact that firm contractors are captive clients, while interruptible customers are not. Now, we derive the access charges and get:

$$a^F = C_{NQ^F} + \frac{\lambda}{1+\lambda}\frac{p_E^F}{\hat{\eta}_E^F} \quad \text{and} \quad a^{NF} = C_{NQ^{NF}} + \frac{\lambda}{1+\lambda}\frac{p_E^{NF}}{\hat{\eta}_E^{NF}}$$

We straightforward see that the tariff of firm access (intended to satisfy firm final wholesale customers) must be higher that the one intended for interruptible access.

B. Symmetric Information Case: Peak Load Pricing

Up to now, we have followed the assumption of slackness in the capacity constraint of the pipeline. Now, we are interested in how the multiproduct background studied in the above subsection, help us to analyze a problem directly associated to allocative efficiency, as it is the peak-load pricing in networks. To do so, we assume there are two classes of independent demands, (i) low-peak, and (ii) high-peak for both access and final transportation services. This means that

$\mathbf{q}_I = (q_I^{LD}, q_I^{HD})$ $\mathbf{q}_E = (q_E^{LD}, q_E^{HD})$ $\mathbf{q}_A = (q_A^{LD}, q_A^{HD})$ will represent the vector of quantities, and

$\mathbf{p}_I = (p_I^{LD}, p_I^{HD})$ $\mathbf{p}_E = (p_E^{LD}, p_E^{HD})$ $\mathbf{a} = (a^{LD}, a^{HD})$ relate to the vector of prices.

Under this circumstances we assume the structure of Laffont-Tirole (1993, Ch. 3) where it is said that the capacity cost for the incumbent is unknown, while the marginal cost is known. This creates the following changes in the gas utility cost functions (upstream and downstream segment):

$$C_N = C_N(\beta, e_N, q_I + q_E) = c_N\left(q_I^{LD} + q_I^{HD} + q_E^{LD} + q_E^{HD}\right) + \Phi_N\left(\beta, e_N, q_I^{HD} + q_E^{HD}\right) \quad (24)$$

$$C_S = C_S(\beta, e_S, \mathbf{q_I}) = C_S\left(\beta, e_S, q_I^{LD}, q_I^{HD}\right) \quad (25)$$

Here we have that the regulator's optimization program is identical to the one described in Model 2 under complete information, and gives the next outcomes

$$\frac{p_I^{LD} - c_N - C_{Sq_I^{LD}}}{p_I^{LD}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I^{LD}}\left(\frac{\eta_I^{LD}\eta_E^{LD} + \eta_I^{LD}\eta_{IE}^{LD}}{\eta_I^{LD}\eta_E^{LD} - \eta_{IE}^{LD}\eta_{EI}^{LD}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^{LD}} \quad (26)$$

$$\frac{p_E^{LD} - c_N - c_E}{p_E^{LD}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_E^{LD}}\left(\frac{\eta_I^{LD}\eta_E^{LD} + \eta_E^{LD}\eta_{EI}^{LD}}{\eta_I^{LD}\eta_E^{LD} - \eta_{IE}^{LD}\eta_{EI}^{LD}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E^{LD}} \quad (27)$$

$$\frac{p_I^{HD} - c_N - \Phi_{NQ^{HD}} - C_{Sq_I^{HD}}}{p_I^{HD}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_I^{HD}}\left(\frac{\eta_I^{HD}\eta_E^{HD} + \eta_I^{HD}\eta_{IE}^{HD}}{\eta_I^{HD}\eta_E^{HD} - \eta_{IE}^{HD}\eta_{EI}^{HD}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^{HD}} \quad (28)$$

$$\frac{p_E^{HD} - c_N - \Phi_{NQ^{HD}} - c_E}{p_E^{HD}} = \frac{\lambda}{1+\lambda}\frac{1}{\eta_E^{HD}}\left(\frac{\eta_I^{HD}\eta_E^{HD} + \eta_E^{HD}\eta_{EI}^{HD}}{\eta_I^{HD}\eta_E^{HD} - \eta_{IE}^{HD}\eta_{EI}^{HD}}\right) = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E^{HD}} \quad (29)$$

As in the other models, the access charges are obtained with the help of the constant returns to scale technology of the entrants,

$$a_E^{LD} = c_N + \frac{\lambda}{1+\lambda}\frac{p_E^{LD}}{\hat{\eta}_E^{LD}} \quad (30)$$

$$a_E^{HD} = c_N + \Phi_{NQ^{HD}} + \frac{\lambda}{1+\lambda}\frac{p_E^{HD}}{\hat{\eta}_E^{HD}} \quad (31)$$

This implies that access in peak-demand states of nature should be priced higher than in cases of idle pipeline's capacity, and most include the marginal expanding capacity cost.

C. Asymmetric Information Case[25]: Peak Load Pricing

In this setting we apply the same methodology of subsection 5.1, due to the independence between the peak and non-peak demands.

25 In this section, we ignore the asymmetric information case of the reliability differentiation, because if we maintain our assumptions for the perfect information case, the model will yield the same results of the single product case.

It is important, to highlight that in the case of the non-peak demand we lose some fraction of the informational rent given to the gas utility, as will be shown in the next equation,

$$\frac{p_I^{LD}-c_N-C_{Sq_I^{LD}}}{p_I^{LD}}=\frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^{LD}}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_I^{LD}}\left(\frac{\partial}{\partial Q^{LD}}\left(-\frac{\Phi_{N\beta}(\beta,e_N,Q^{HD})}{\Phi_{Ne_N}(\beta,e_N,Q^{HD})}\right)+\frac{\partial}{\partial q_I^{LD}}\left(-\frac{C_{S\beta}}{C_{Se_S}}\right)\right)$$

Therefore, we obtain that,

$$\frac{p_I^{LD}-c_N-C_{Sq_I^{LD}}}{p_I^{LD}}=\frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^{LD}}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_I^{LD}}\left[\frac{\partial}{\partial q_I^{LD}}\left(-\frac{C_{S\beta}}{C_{Se_S}}\right)\right] \quad (32)$$

$$\frac{p_E^{LD}-c_N-c_E}{p_E^{LD}}=\frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E^{LD}} \quad (33)$$

$$\frac{p_I^{HD}-c_N-\Phi_{NQ^{HD}}-C_{Sq_I^{HD}}}{p_I^{HD}}=\frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_I^{HD}}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_I^{HD}}\left(\frac{\partial}{\partial Q^{HD}}\left(-\frac{\Phi_{N\beta}}{\Phi_{Ne_N}}\right)+\frac{\partial}{\partial q_I^{HD}}\left(-\frac{C_{S\beta}}{C_{Se_S}}\right)\right) \quad (34)$$

$$\frac{p_E^{HD}-c_N-\Phi_{NQ^{HD}}-c_E}{p_E^{HD}}=\frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_E^{HD}}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\frac{\psi'(\bullet)}{p_E^{HD}}\left(\frac{\partial}{\partial Q^{HD}}\left(-\frac{\Phi_{N\beta}}{\Phi_{Ne_N}}\right)\right) \quad (35)$$

Therefore, the access prices are represented by,

$$a_E^{LD}=c_N+\frac{\lambda}{1+\lambda}\frac{p_E^{LD}}{\hat{\eta}_E^{LD}}$$

$$a_E^{HD}=c_N+\Phi_{NQ^{HD}}+\frac{\lambda}{1+\lambda}\frac{p_E^{HD}}{\hat{\eta}_E^{HD}}+\frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\psi'(\bullet)\left(\frac{\partial}{\partial Q^{HD}}\left(-\frac{\Phi_{N\beta}}{\Phi_{Ne_N}}\right)\right)$$

As we can see the incentive-price dichotomy holds per-se in the case of access charges in the non-peak situation. Conversely, in the asymmetric information case, is we keep on the positivity assumption of the incentive correction term, the access charge in the case of peak-demand should be increased because of the regulator's desire to extract the informational rent earned by the gas utility in the administration of the pipeline capacity costs.

VI. MODEL 3: NONLINEAR PRICING

Here we will consider not only the asymmetry of information of the last sections, but also the possibility that the gas utility is ignorant of the demand characteristics of individual customers and must thus practice second-degree price discrimination. First, we assume that the gas utility sells a single homogeneous product (transportation service) to the final wholesale consumers. The entrants, once more, produce and imperfect substitute of this service. Additionally, we will take for granted that there are two types of wholesale consumers: (i) those who are willing to sign firm transportation contracts (in proportion α^F), and (ii) those who prefer to establish interruptible contracts (in proportion α^{NF})[26].

Wholesale customers of type (^{F}) are considered as "high-valuation consumers" in the sense that they rate highly the transportation service. This implies that this group may be composed by captive customers like large end consumers that have designed their infrastructure with no possibilities (or very limited) of fuel substitution; and local distribution companies which have the obligation, under state regulation, to guarantee supplies on behalf of their customers[27]. Conversely, clients of type (^{NF}) correspond to industrial enterprises with fuel-switching capability, and marketers (as intermediaries between producers and end-users) who generally hold a diversified mix of transportation service contracts of which interruptible and released capacity account for about two thirds of their total capacity needs (*See* IEA (1998)).

We also keep on the assumption that the gas utility knows more about its own technology than the regulator, which is represented by the productivity parameter β, and the effort of reducing costs (e_N, e_S).

Consequently, we have to redefine some of our variables,

$$V(\mathbf{q}_I(\mathbf{p}_I,\mathbf{p}_E);\mathbf{q}_E(\mathbf{p}_I,\mathbf{p}_E)) = \alpha^F V^F\left(q_I^F\left(p_I^F,p_E^F\right);q_E^F\left(p_I^F,p_I^F\right)\right) + \alpha^{NF} V^{NF}\left(q_I^{NF}\left(p_I^{NF},p_E^{NF}\right);q_E^{NF}\left(p_I^{NF},\dot{p}_I^{NF}\right)\right)$$

$$\frac{\partial V^F(\bullet)}{\partial q_j^F} > \frac{\partial V^{NF}(\bullet)}{\partial q_j^{NF}} \quad \text{and} \quad \frac{\partial V^F(\bullet)}{\partial q_j^{NF}} > \frac{\partial V^{NF}(\bullet)}{\partial q_j^{NF}} \quad \forall\ j = I, E \qquad \text{(Single-Crossing Property)}$$

Additionally, to simplify our notation we will say that

$$V^F\left(q_I^F\left(p_I^F,p_E^F\right);q_E^F\left(p_I^F,p_E^F\right)\right) = \theta^F V\left(q_I^F\left(p_I^F,p_E^F\right);q_E^F\left(p_I^F,p_I^F\right)\right) \qquad \text{where } \theta^F > \theta^{NF}$$

$$V^{NF}\left(q_I^{NF}\left(p_I^{NF},p_E^{NF}\right);q_E^{NF}\left(p_I^{NF},p_E^{NF}\right)\right) = \theta^{NF} V\left(q_I^{NF}\left(p_I^{NF},p_E^{NF}\right);q_E^{NF}\left(p_I^{NF},p_E^{NF}\right)\right) \quad (^{28}) \qquad (36)$$

$$Q_I = \alpha^F q_I^F + \alpha^{NF} q_I^{NF} \quad Q_E = \alpha^F q_E^F + \alpha^{NF} q_E^{NF} \quad Q = Q_I + Q_E$$

---

26 $\alpha^F + \alpha^{NF} = 1$

27 A poor storage infrastructure to manage demand and supply imbalances also constitutes a reason for this behavior.

28 We have to mention that $\theta^F V'(\bullet) = p_j^F$ and $\theta^{NF} V'(\bullet) = p_j^{NF}$

and we will achieve the following maximization program:

$$\begin{aligned}\text{Max}W=\int_{\underline{\beta}}^{\bar{\beta}}\Big\{&\alpha^F\theta^F V\big(q_I^F(p_I^F(\beta),p_E^F(\beta)),q_E^F(p_I^F(\beta),p_E^F(\beta))\big)+\alpha^{NF}\theta^{NF}V\big(q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta)),q_E^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)\\&-(1+\lambda)\big[\psi(e_N(\beta),e_S(\beta))+C_N\big(\beta,e_N(\beta),\alpha^F\big(q_I^F(p_I^F(\beta),p_E^F(\beta))+q_E^F(p_I^F(\beta),p_E^F(\beta))\big)\\&+\alpha^{NF}\big(q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))+q_E^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)\big)\\&+C_S\big(\beta,e_S(\beta),\alpha^F q_I^F(p_I^F(\beta),p_E^F(\beta))+\alpha^{NF}q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)+c_E q_E(p_I(\beta),p_E(\beta))\big]\\&-\lambda U_I(\beta)+\lambda\big[\alpha^F\big(T_I\big(q_I^F(p_I^F(\beta),p_E^F(\beta))\big)+T_E\big(q_E^F(p_I^F(\beta),p_E^F(\beta))\big)\big)\\&+\alpha^{NF}\big(T_I\big(q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)+T_E\big(q_E^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)\big)\big]\Big\}dF(\beta)\end{aligned} \tag{37}$$

s.t. $$\dot{U}_I(\beta)=-\psi'(e_N,e_S)\left(\frac{\partial E_N}{\partial\beta}(\bullet)+\frac{\partial E_S}{\partial\beta}(\bullet)\right) \tag{38}$$

$$U_I(\bar{\beta})\geq 0 \tag{39}$$

$$\theta^F V(q_I^F,q_E^F)-\big(T_I(q_I^F)+T_E(q_E^F)\big)\geq\theta^F V(q_I^{NF},q_E^{NF})-\big(T_I(q_I^{NF})+T_E(q_E^{NF})\big)\quad (IC^F) \tag{40}$$

$$\theta^{NF}V(q_I^{NF},q_E^{NF})-\big(T_I(q_I^{NF})+T_E(q_E^{NF})\big)\geq\theta^{NF}V(q_I^F,q_E^F)-\big(T_I(q_I^F)+T_E(q_E^F)\big)\quad (IC^{NF}) \tag{41}$$

$$\theta^F V(q_I^F,q_E^F)-\big(T_I(q_I^F)+T_E(q_E^F)\big)\geq 0\quad (IR^F) \tag{42}$$

$$\theta^{NF}V(q_I^{NF},q_E^{NF})-\big(T_I(q_I^{NF})+T_E(q_E^{NF})\big)\geq 0\quad (IR^{NF}) \tag{43}$$

Where the tariff structure will be assumed as the traditional two-part tariff applied in the gas transportation contracts, where the fixed fee correspond to the "capacity charge" and the marginal price to the "throughput (commodity) charge" (For more on this, *See* Section A and B of this document). Therefore we have that,

$$T_j(q_j^\ell)=P(\theta^\ell)+p_j^\ell q_j^\ell\quad\forall\,\ell={}^{F,NF}\quad\text{and}\quad\forall\,j={}_{I,E} \tag{44}$$

A. Informational Symmetry about Demand Parameters

Under this assumption (perfect discrimination), the gas utility is able to observe directly the consumer's taste parameter about reliability and as a consequence, constraints (42) and (43) will be binding. Therefore, the remaining maximization program is expressed as,

$$\begin{aligned}\text{Max }W=\int_{\underline{\beta}}^{\bar{\beta}}\Big\{&\alpha^F\theta^F(1+\lambda)V\big(q_I^F(p_I^F(\beta),p_E^F(\beta)),q_E^F(p_I^F(\beta),p_E^F(\beta))\big)+\alpha^{NF}\theta^{NF}(1+\lambda)V\big(q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta)),q_E^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)\\&-(1+\lambda)\big[\psi(e_N(\beta),e_S(\beta))+C_N\big(\beta,e_N(\beta),\alpha^F\big(q_I^F(p_I^F(\beta),p_E^F(\beta))+q_E^F(p_I^F(\beta),p_E^F(\beta))\big)\\&+\alpha^{NF}\big(q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))+q_E^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)\big)\\&+C_S\big(\beta,e_S(\beta),\alpha^F q_I^F(p_I^F(\beta),p_E^F(\beta))+\alpha^{NF}q_I^{NF}(p_I^{NF}(\beta),p_E^{NF}(\beta))\big)+c_E q_E(p_I(\beta),p_E(\beta))\big]-\lambda U_I(\beta)\Big\}dF(\beta)\end{aligned}$$

$$\text{s.t.} \qquad \dot{U}_I(\beta) = -\psi'(e_N, e_S)\left(\frac{\partial E_N}{\partial \beta}(\bullet) + \frac{\partial E_S}{\partial \beta}(\bullet)\right)$$

$$U_I(\bar{\beta}) \geq 0$$

To obtain the first order conditions with respect to prices we solve again

$$\begin{cases} \dfrac{\partial H}{\partial p_I^F} = 0 & \dfrac{\partial H}{\partial p_E^F} = 0 \\ \dfrac{\partial H}{\partial p_I^{NF}} = 0 & \dfrac{\partial H}{\partial p_E^{NF}} = 0 \end{cases}$$

$$\begin{bmatrix} \dfrac{\partial q_I^F}{\partial p_I^F} & \dfrac{\partial q_E^F}{\partial p_I^F} & 0 & 0 \\ \dfrac{\partial q_I^F}{\partial p_E^F} & \dfrac{\partial q_E^F}{\partial p_E^F} & 0 & 0 \\ 0 & 0 & \dfrac{\partial q_I^{NF}}{\partial p_I^{NF}} & \dfrac{\partial q_E^{NF}}{\partial p_I^{NF}} \\ 0 & 0 & \dfrac{\partial q_I^{NF}}{\partial p_E^{NF}} & \dfrac{\partial q_E^{NF}}{\partial p_E^{NF}} \end{bmatrix} \begin{bmatrix} \alpha^F\left(p_I^F - C_{NQ} - C_{Sq_I}\right) - \alpha^F I_I \\ \alpha^F\left(p_E^F - C_{NQ} - c_E\right) - \alpha^F I_E \\ \alpha^{NF}\left(p_I^F - C_{NQ} - C_{Sq_I}\right) - \alpha^{NF} I_I \\ \alpha^{NF}\left(p_E^{NF} - C_{NQ} - c_E\right) - \alpha^{NF} I_E \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad \text{where,}$$

$$\begin{aligned} I_I &= \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\psi'(e_N(\beta), e_S(\beta))\left(\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right) + \frac{\partial}{\partial Q_I}\left(-\frac{\partial C_S}{\partial \beta}\Big/\frac{\partial C_S}{\partial e_S}\right)\right) \\ I_E &= \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}\psi'(e_N(\beta), e_S(\beta))\frac{\partial}{\partial Q}\left(-\frac{\partial C_N}{\partial \beta}\Big/\frac{\partial C_N}{\partial e_N}\right) \end{aligned} \tag{45}$$

$$\frac{p_I^\ell - C_{NQ} - C_{Sq_I}}{p_I^\ell} = \frac{I_I}{p_I^\ell} \quad \forall\, \ell = ^{F,NF} \tag{46}$$

$$\frac{p_E^\ell - C_{NQ} - c_E}{p_E^\ell} = \frac{I_E}{p_E^\ell} \quad \forall\, \ell = ^{F,NF} \tag{47}$$

If we assume that the Incentive-Pricing dichotomy is accomplished, the above results imply that with respect to the tariff schedule; the gas utility and the entrants must set the "commodity charge" equal to the marginal cost of providing the final units of gas in the wholesale market. Regarding to the fixed fee or "capacity charge", it should be equal to the customer's net surplus after paying the "commodity charge". Following, the assumptions given at the beginning of this section, the capacity charge is higher for the high-valuation consumers. (*See* Tirole (1988)).

This result is consistent with the tradition in the natural gas market of setting a demand charge, which recovers most of the fixed costs of transportation, and a usage charge, which recovers variable (or operational) costs. Additionally, the fact that fixed costs are allocated between firm and interruptible services on the basis of the ratio of firm to interruptible service loads in the pipeline shows the theoretical relationship between the fixed fee of the high-valuation consumers and the low-ones.

Finally, just as in preceding sections, the marginal access charge could be expressed as,

$$a_E^{NF} = a_E^F = C_{NQ} + I_E \tag{48}$$

because the discrimination is done throughout the "capacity charge". However, as the gas utility does not observe perfectly the characteristics of its customers, this allocation cannot be implemented. Additionally, the existence of a secondary transportation market will generate in some situations the incentive for interruptible contractors to mimic being firm ones to have spare capacity that could be released in peak-demand periods.

B. Double Informational Asymmetry

In this situation, we consider that it is impossible for high valuation customers in the short and medium-term to modify their substituability boundaries. If it were possible to do so, the high valuation consumer could "bypass" the gas transportation service in two ways: (i) a complete way in which he decides to leave the gas transportation market[29], and (ii) a partial one, where he stays in the market as an interruptible contractor and acquire a fuel-switching technology. In both cases, he would incur in a fixed cost σ and a constant marginal cost φ of using the alternative sources. Therefore, to formalize this assumption, we state the following:

$$V_*^F(\bullet) = \max_{q_m} \left[\theta^F V(q_m) - \sigma - \varphi q_m\right] \leq 0$$

$$V_{**}^F(\bullet) = \max_{q_I^{NF}, q_E^{NF}, q_m} \left[\theta^F V\left(q_I^{NF}, q_E^{NF}, q_m\right) - p_I^{NF} q_I^{NF} - p_E^{NF} q_E^{NF} - \sigma - \varphi q_m\right] \leq 0$$

Those technological conditions, and the legal unfeasibility of non-serving the final retail consumers in the case of LDC (High penalties by the Regulator) determine that (IC^F) can be neglected because it is never binding. Thus, as it can easily be shown, (IR^F) has to be binding. (*See* Laffont and Tirole (1993, Ch 6)).

Concerning to the interruptible contractors, they already acquired the switching technology, so the threat of leaving the transportation market is not relevant in this case. On the contrary, as we mentioned in the last part of subsection A, the presence

29 This could be the case of purchasing liquefied natural gas which only is more profitable in extremely long distances. This fact also reduces the possibilities of complete bypass.

of a secondary transportation market, and the implicit opportunities of arbitrage, motivates the interruptible contractors to appear to be firm or captive customers. In order to avoid the distortion over allocative efficiency, generated by this strategy, we assume that (IC^{NF}) is binding. These assumptions imply

$$
\begin{aligned}
T_I\left(q_I^F\right)+T_E\left(q_E^F\right) &= \theta^F V\left(q_I^F, q_E^F\right) \\
T_I\left(q_I^{NF}\right)+T_E\left(q_E^{NF}\right) &= \theta^F V\left(q_I^F, q_E^F\right)-\theta^{NF} V\left(q_I^F, q_E^F\right)+\theta^{NF} V\left(q_I^{NF}, q_E^{NF}\right)
\end{aligned}
$$

Therefore, the remaining maximization program is expressed as,

$$
\begin{aligned}
\text{Max } W = \int_{\underline{\beta}}^{\bar{\beta}} \Big\{ & \alpha^F\theta^F V\left(q_I^F\left(p_I^F(\beta), p_E^F(\beta)\right), q_E^F\left(p_I^F(\beta), p_E^F(\beta)\right)\right)+\alpha^{NF}\theta^{NF} V\left(q_I^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right), q_E^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right)\right) \\
& -(1+\lambda)\Big[\psi\left(e_N(\beta), e_S(\beta)\right)+C_N\Big(\beta, e_N(\beta), \alpha^F\left(q_I^F\left(p_I^F(\beta), p_E^F(\beta)\right)+q_E^F\left(p_I^F(\beta), p_E^F(\beta)\right)\right) \\
& +\alpha^{NF}\left(q_I^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right)+q_E^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right)\right)\Big) \\
& +C_S\left(\beta, e_S(\beta), \alpha^F q_I^F\left(p_I^F(\beta), p_E^F(\beta)\right)+\alpha^{NF} q_I^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right)\right)+c_E q_E\left(p_I(\beta), p_E(\beta)\right)\Big] \\
& -\lambda U_I(\beta)+\lambda\Big[\theta^F V\left(q_I^F\left(p_I^F(\beta), p_E^F(\beta)\right), q_E^F\left(p_I^F(\beta), p_E^F(\beta)\right)\right) \\
& +\alpha^{NF}\left(\theta^{NF} V\left(q_I^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right), q_E^{NF}\left(p_I^{NF}(\beta), p_E^{NF}(\beta)\right)\right)-\theta^{NF} V\left(q_I^F\left(p_I^F(\beta), p_E^F(\beta)\right), q_E^F\left(p_I^F(\beta), p_E^F(\beta)\right)\right)\right)\Big]\Big\} dF(\beta)
\end{aligned}
$$

$$
\text{s.t.} \qquad \dot{U}_I(\beta)=-\psi'(e_N, e_S)\left(\frac{\partial E_N}{\partial\beta}(\bullet)+\frac{\partial E_S}{\partial\beta}(\bullet)\right)
$$

$$
U_I\left(\bar{\beta}\right)\geq 0
$$

$$
\begin{bmatrix}
\frac{\partial q_I^F}{\partial p_I^F} & \frac{\partial q_E^F}{\partial p_I^F} & 0 & 0 \\
\frac{\partial q_I^F}{\partial p_E^F} & \frac{\partial q_E^F}{\partial p_E^F} & 0 & 0 \\
0 & 0 & \frac{\partial q_I^{NF}}{\partial p_I^{NF}} & \frac{\partial q_E^{NF}}{\partial p_I^{NF}} \\
0 & 0 & \frac{\partial q_I^{NF}}{\partial p_E^{NF}} & \frac{\partial q_E^{NF}}{\partial p_E^{NF}}
\end{bmatrix}
\begin{bmatrix}
\alpha^F\left(p_I^F-C_{NQ}-C_{Sq_I}\right)-\alpha^F I_I-\frac{\lambda}{1+\lambda}\alpha^{NF}\left(\theta^{NF}V'(\bullet)-\theta^F V'(\bullet)\right) \\
\alpha^F\left(p_E^F-C_{NQ}-c_E\right)-\alpha^F I_E-\frac{\lambda}{1+\lambda}\alpha^{NF}\left(\theta^{NF}V'(\bullet)-\theta^F V'(\bullet)\right) \\
\alpha^{NF}\left(p_I^F-C_{NQ}-C_{Sq_I}\right)-\alpha^{NF} I_I \\
\alpha^{NF}\left(p_E^{NF}-C_{NQ}-c_E\right)-\alpha^{NF} I_E
\end{bmatrix}
=
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}
$$

where,

$$
\frac{p_I^F-C_{NQ}-C_{Sq_I}}{p_I^F}=-\frac{\lambda}{1+\lambda}\frac{\alpha^{NF}}{\alpha^F}\left[\frac{\theta^F-\theta^{NF}}{\theta^F}\right]+\frac{I_I}{p_I^F} \tag{49}
$$

$$
\frac{p_E^F-C_{NQ}-c_E}{p_E^F}=-\frac{\lambda}{1+\lambda}\frac{\alpha^{NF}}{\alpha^F}\left[\frac{\theta^F-\theta^{NF}}{\theta^F}\right]+\frac{I_E}{p_E^F} \tag{50}
$$

$$
\frac{p_I^{NF}-C_{NQ}-C_{Sq_I}}{p_I^{NF}}=\frac{I_I}{p_I^{NF}} \tag{51}
$$

$$
\frac{p_E^{NF}-C_{NQ}-c_E}{p_E^{NF}}=\frac{I_E}{p_E^{NF}} \tag{52}
$$

And similarly, the marginal access charges are represented by

$$a_E^F = C_{NQ} - \frac{\lambda}{1+\lambda}\frac{\alpha^{NF}}{\alpha^F}\left[p_E^{NF} - \left(\partial V^{NF}/\partial q_E^F\right)\right] + I_E \tag{53}$$

$$a_E^{NF} = C_{NQ} + I_E \tag{54}$$

which in general terms calls for discrimination in the access charges to preserve the consistency of this policy in the final wholesale market. If we take for granted the Incentive-pricing dichotomy, (49)-(52) mean that the marginal price of gas provided in the wholesale market is fixed in such a way that it is equal to its related marginal cost for the interruptible customers. On the contrary, the marginal price or "throughput charge" has to be lower than the marginal cost for the firm contractors so as to prevent that the non-firm ones mimic to be captive customers.

To find a simple way to justify this result, we have to remember that the tariff structure initially assumed corresponds to a two-part tariff (Eq. 44) where the marginal price is a decreasing function of the fixed fee[30] (*See* Laffont and Tirole (2000), and also Tirole (1988)). In this way, the lower than marginal cost "commodity charge" for the firm customers bring about a higher "capacity charge" that only can be supported by the firm customers. This is due to the technological and legal boundaries of this group of customers.

Regarding, to the efficient access charges, if the tariff is increasing and concave, the efficient access charge paid by the entrants is a decreasing and convex function of the "capacity charge" (fixed fee) paid by the final wholesale customers.

Additionally, if we presuppose that (i) the secondary contracting is absolutely forbidden, and (ii) the amount of gas procured by interruptible customers is strictly lower than the firm shipments; the two-part tariff implemented for firm customers is always dominated for the interruptible contractors. However, two-part tariffs do not completely avoid the possibilities of arbitrage, and therefore some limited arbitrage may occur, depending on the relative cost and benefit. In the case of a constrained capacity activity; like gas transportation, there are large opportunities of making profits by reselling contracts taking advantage of locational and time price differences.

Thus, under the above conditions two-part tariffs are not optimal in preventing the interruptible contractors mimicking to be firm customers in the primary transportation market. As a consequence, the proportion of non-firm customers diminishes as the secondary market is developed. Therefore, as $\alpha^{NF} \to 0$ the distortionary term in (49)-(50) disappears and the "transportation charge" for the firm contracts is priced at the marginal cost.

This fact is consistent with some trends of the empirical transportation market. Following IEA (1998), there has been a sharp decline in the share of interruptible

30 The concavity of the tariff structure is another justification for this result.

service, whereby the pipeline company has the right to withdraw capacity at short notice to ensure that sufficient capacity is available for customers who have reserved firm service. This service has been largely replaced by primary firm transportation. As an example, interruptible transportation accounted for only 14% of total US gas deliveries in 1995, compared with over half in the mid-1980s. Conversely, released capacity traded on the secondary market now represents a significant element in the transportation market.

Covering another topic, in theory, it is expected that the price of interruptible contracts reflect the short-run marginal cost of supplying the service, while, for firm service, the price has to signal the long-run marginal transportation cost (*See* definitions in subsection C). In this framework, this is adjustment is partially reached for the interruptible contracts. In this line, we consider that this result must arrive because we do not take into account the impact of the reliability provision over the cost structure. In other words, we ignore the fact that the marginal cost decreases as the level of reliability diminishes.

As a consequence, for the implementation of optimal nonlinear pricing structures, it is important to find a tariff structure that assigns simultaneously prices to both reliability and quantities in the transportation contacts; which will be studied in the next section.

VII. MODEL 4: PRIORITY PRICING

Now we explore the possibility of taking advantage from the heterogeneity of the customers in the reliability dimension. In terms of access policy, this means that the incumbent would be interested in assigning differentiated prices for gas transportation contracts in function of the reliability of supply that they provide. This measure will help the gas utility to ration efficiently its limited capacity and additionally to extract a larger proportion of its customers' surplus. In addition to the incumbent, as we have assumed all over this paper that the entrants do not have monopoly power, they will apply the same pricing principles to their final customers (wholesale traders).

In the gas transportation market, the first best solution determines that the price of the traded contracts be varied continually to keep demand within capacity, while ensuring an efficient allocation of scarce supplies (in other words, a short-run marginal cost pricing). As we have mentioned before this property can be approximated by establishing a secondary transportation market for idle capacity, as it has been done in the U.S. and the U.K. (*See* Juris (1998a), (1998b)).

However, Wilson (1989) sustains that, spot pricing has a lot of difficulties in the presence of limited possibilities of storage. The most frequent reasons are technological boundaries and pervasive transaction costs. It results difficult or expensive to inform a customer continually about prices and to monitor the time pattern of purchases, even if the right prices to support capacity utilization and to prevent congestion were known by the gas utility. Similarly, it is expensive for customers to monitor prices continually and adapt their purchases. As a consequence of these limitations, it has been traditional in the gas industry to set a fixed price for transportation contracts that generates idle capacity in some periods and allocative inefficiencies when customers' preferences over reliability differ.

As an alternative to the hard-to-set spot markets, Chao and Wilson (1987) and Wilson(1989) propose a priority pricing mechanism that approximates in almost all dimensions the gains obtained by the short run marginal pricing. In this way, the contracts dealt in the primary gas transportation market will be called *priority service* contracts that specify each customer's priority in obtaining service.

In the gas industry, in the simplest design, each supplier (shipper) selects between interruptible and firm service, offered at different prices. In addition to the direct charge for transportation, a customer pays a premium depending on the priority class he selects. In the simplest case that has been implemented in the gas industry, two priorities are offered and each customer selects a base portion of his load to assign to the first priority and the residual to the second priority.

Regarding to the number of priority classes, it is constrained by the technology of supply and the costs of market organization. However, Chao and Wilson (1987) show that the incremental welfare gains from priority service decline rapidly as the number of priority classes increases. Thus, a few priority classes can capture most of the potentials from priority service.

Priority service causes efficiency gains by serving customers consistent with their valuation of reliability or cost of interruption. The perceived advantage, is the increased product differentiation the wholesale shipper or the entrant will find in the primary transportation market[31]. In addition to the advantages for customers, these contracts provide the gas utility of tools (like reserve capacity) to meet in a profitable way high-demand periods. This means that under this scheme, the monopolist is able to substitute low-priority contracts that reflect a customers' low-valuation for expensive additions to capacity required to sustain reliable service to high-value end uses.

The role of pricing in this new scenario is to achieve an efficient allocation in the case that each consumer knows privately its type. This implies the need to induce consumers to reveal their type through their selections of reliability conditions from a menu of contracts. Finally, with priority service the gas utility can replace partially the "capacity" charge initially designed to satisfy the breakeven constraint, by priority charges.

A. General Structure

Initially, we assume the absence of a spot market that resolves the asymmetries generated by the difference between the information known to customers (each one

31 This mechanism differs form ordinary product differentiation in that the qualities obtained are endogenous: they depend on how many other consumers select the same and higher priorities.

knows his type) and the information known to the gas utility (the available capacity). Also the secondary market is forbidden by the regulator.

We follow the methodology of Wilson (1993, Ch. 13) for priority service pricing. We start by saying that the incumbent offers n different reliability contracts to both the entrants and the final wholesale consumers. Those contracts[32] are indexed by $\ell = 1,\ldots,n$, and linked to each contract ℓ, there is a service reliability r^ℓ and an expected sub-cost C^ℓ. Regarding to the reliability r^ℓ, it decreases with ℓ, and it also corresponds to a discrete distribution function[33] characterized by

$$\Pr ob\left(r^\ell \le r^\ell\right) = F\left(r^\ell\right) = r^\ell \quad \Rightarrow \quad f\left(r^\ell\right) = s^\ell = r^\ell - r^{\ell+1}$$

In relation to the cost structure, in terms of our general notation we have

$$C_N = C_N\left(\beta, \mathbf{e}_N, \mathbf{q}_I + \mathbf{q}_E\right) = C_N\left(\beta, e^0, e^1, \ldots, e^n, \mathbf{q}_I + \mathbf{q}_E\right) = C_N^0\left(\beta, e^0\right)$$

$$+ \sum_{\ell=1}^{n} C_N^\ell\left(\beta, e^\ell, q_I^\ell + q_E^\ell\right) \tag{55}$$

$$C_S = C_S\left(\beta, \mathbf{e}_S, \mathbf{q}_I\right) = C_S\left(\beta, e^1, \ldots, e^n, \mathbf{q}_I\right) = \sum_{\ell=1}^{n} C_S^\ell\left(\beta, e^\ell, q_I^\ell\right) \tag{56}$$

where C_N^0 corresponds to a fixed cost associated to the pipeline construction, and C^ℓ is the sub-cost associated to each reliability contract. For simplicity of analysis, we will assume that the sub-cost is considered as a result of a constant marginal cost technology in each production set[34]. Thus,

$$C_N = C_N^0\left(\beta, e^0\right) + \sum_{\ell=1}^{n} c_N^\ell\left(q_I^\ell + q_E^\ell\right) \tag{57}$$

$$C_S = \sum_{\ell=1}^{n} c_S^\ell q_I^\ell \tag{58}$$

Therefore, the incremental cost of an augmentation in reliability ℓ, in both the access and the final wholesale transactions, is defined as

$$\delta_N^\ell = \frac{c_N^\ell - c_N^{\ell+1}}{r^\ell - r^{\ell+1}} \quad \text{and} \quad \delta_S^\ell = \frac{c_S^\ell - c_S^{\ell+1}}{r^\ell - r^{\ell+1}},$$

32 Here, each contract represents a different product.

33 This is a generalization of the structure of discrimination sketched in section 5.2, where it was assumed that there were two types of reliabilities (firm and interruptible service).

34 The fact that c_j^ℓ is a expected measure of the effective marginal cost is represented by $E\left[\frac{c_j^\ell}{r^\ell}\right] = F\left(r^\ell\right)\frac{c_j^\ell}{r^\ell} = c_j^\ell$

and this function is decreasing in ℓ, which implies that it is less costly to serve low-priority contracts than high-priority ones (this assumption has not been taken into account in section VI). For notational concerns we assume that there exists a contract $n+1$ with $r^{n+1}=0$ and $C_j^{n+1}=0$

Finally, we keep on the assumption that the entrants' technology is defined by constant returns to scale, and they still produce an imperfectly substitute to the gas offered by the incumbent in the wholesale market. Thus, the profit function expressed in (6) can be rewritten as

$$\Pi_E=\sum_{\ell=1}^{n}\left(p_E^\ell-c_E^\ell-a^\ell\right)q_E^\ell$$

On the other hand, each customer preferences are identified by a nonnegative number θ that represents the customer valuation for each contract reliability[35]. The population of customer is taken to be a continuum over the support $(\underline{\theta},\overline{\theta})$. Thus, if $G(\theta)$ represents the distribution of types in the population, then also $G(\theta)$ is a measure of types not exceeding (θ). Note that $G(\overline{\theta})=1$ and $G(\underline{\theta})=0$. Although it is not necessary, we make the simplifying assumption that there are no large set of customers of the same type. Furthermore, this distribution function satisfies the traditional monotone hazard rate assumption $d\left[\frac{g(\theta)}{1-G(\theta)}\right]\Big/d\theta\geq 0$.

Moreover, $V(q_I(\theta),q_E(\theta),\theta)$ represents in this environment the gross consumers' surplus[36] and it preserves the properties expressed in (3). It is also assumed to be separable and increasing in both quantities and willingness to pay for reliability. The concavity assumption is also fulfilled. Therefore,

$$\frac{\partial V(\bullet)}{\partial q_j^\ell}\geq 0,\quad \frac{\partial^2 V(\bullet)}{\partial q_j^\ell\partial q_j^m}\leq 0,\quad \frac{\partial V(\bullet)}{\partial\theta}\geq 0,\quad \frac{\partial}{\partial\theta}\left(\frac{\partial V(\bullet)}{\partial q_j^\ell}\right)\geq 0$$

A customer of type θ has a marginal valuation $\upsilon_j(x,\theta)\,\forall\, j=_{I,E}$ for an x-th unit of transportation service if actually delivered (and zero otherwise), assumed to be decreasing in x and increasing in θ.

35 Implicitly, we suppose that the distribution of θ is the same for the set of customers of the incumbent (entrants and wholesale suppliers) and of the entrants (wholesale suppliers).

36 It is important to distinguish between $q_j=\left(q_j^1,\cdots,q_j^n\right)\ \forall\ j=_{I,E}$ that represents the total customer purchase from the set of contracts established by the incumbent or the entrants (measure the reliability effect on consumption decision); and $Q_j^\ell=\sum_{k\leq\ell}q_j^k$ that indicates the number of units assigned reliabilities greater than r^ℓ.

Taking into account all these factors, we can express the consumers' gross surplus as

$$V(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta)=\sum_{j=I,E}\sum_{\ell=1}^{n}\int_0^{q_j^\ell} r^\ell \upsilon_j\left(Q_j^{\ell-1}+x_j,\theta\right)dx_j$$

$$u_I^\ell(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta)\equiv\frac{\partial V(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta)}{\partial q_I^\ell}=\sum_{k=\ell}^{n}s^k\upsilon_I\left(Q_I^k,\theta\right) \text{ and } u_E^\ell(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta)$$

$$=\sum_{k=\ell}^{n}s^k\upsilon_E\left(Q_E^k,\theta\right)$$

where the term inside the integral expresses the "expected" marginal valuation for the additional units of gas transportation service, along the reliability contract ℓ[37].

Before be go to the solving of the program, we should specify that the regulator observes prices, quantities, the cost function, the productivity and the cost reduction parameters of the incumbent. However, the marginal willingness to pay for reliability constitutes a private information of the consumers[38]. This fact has a central role in nonlinear pricing because the optimal payment schedule has to be designed to induce self-selection among the final customers.

Additionally, we change the accounting assumptions of Model 2 (Perfect Information Case), and we assume that the regulator is prohibited from transferring money to the gas utility. In this case, the term in square brackets in equation (5) has to be equal to zero, and therefore

Incumbent's Utility Level $U_I=T_I(\mathbf{q}_I(\theta))-C_I-\psi(\mathbf{e}_N,\mathbf{e}_S)+\sum_{\ell=1}^{n}a^\ell q_E^\ell$ (59)

Consumer's Utility Level $U_C=V(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta)-T_I(\mathbf{q}_I(\theta))-T_E(\mathbf{q}_E(\theta))$ (60)

37 The proof of the result of this derivation is the following

$$V(\bullet)=\sum_{j=I,E}\left(\sum_{\ell=1}^{m-1}\int_0^{q_j^\ell} r^\ell\upsilon\left(Q_j^{\ell-1}+x_j,\theta\right)dx_j+\int_0^{q_j^m} r^m\upsilon\left(Q_j^{m-1}+x_j,\theta\right)dx_j+\sum_{\ell=m+1}^{n}\int_0^{q_j^\ell} r^\ell\upsilon\left(Q_j^{\ell-1}+x_j,\theta\right)dx_j\right)$$

$$\frac{\partial V(\bullet)}{\partial q_j^m}=r^m\upsilon\left(Q_j^m,\theta\right)+\sum_{\ell=m+1}^{n}r^\ell\int_0^{q_j^\ell}\frac{\partial}{\partial q_j^m}\left(\upsilon\left(Q_j^{\ell-1}+x_j,\theta\right)\right)dx_j$$

$$\frac{\partial V(\bullet)}{\partial q_j^m}=r^m\upsilon\left(Q_j^m,\theta\right)+\sum_{\ell=m+1}^{n}r^\ell\left(\upsilon\left(Q_j^\ell,\theta\right)-\upsilon\left(Q_j^{\ell-1},\theta\right)\right)$$ and using the contract q_{n+1} with $r_{n+1}=c_{n+1}=0$

$$\frac{\partial V(\bullet)}{\partial q_j^m}=\sum_{k=m}^{n}s^k\upsilon\left(Q_j^k,\theta\right)$$

38 The different preferences among the customers are reflected in their purchases and the heterogeneity we allow is restricted to an indexing of the consumer's types along a single dimension.

Entrants' Utility Level $\Pi_E = \sum_{\ell=1}^{n} \left(p_E^\ell - c_E^\ell - a^\ell\right) q_E^\ell$ (61)

This implies that the regulator should maximize the expected welfare, constrained to the breakeven condition of the incumbent and the entrants. Though, the second restriction can be omitted due to the constant returns to scale (no fixed costs) technology for the entrants. Therefore

$$\text{Max} \quad E[W] = \int_{\underline{\theta}}^{\bar{\theta}} \left\{U_C + \left(1+\tilde{\lambda}\right)U_I + \Pi_E\right\} dG(\theta)$$

s.t. $\dot{U}_C = V_\theta\left(\mathbf{q_I}(\theta), \mathbf{q_E}(\theta), \theta\right)$, that can be expressed as the following Hamiltonian
$U_C(\cdot) \geq 0 \quad \forall\, \theta$

$$H = \left\{\left(1+\tilde{\lambda}\right)\left[V\left(\mathbf{q_I}(\theta), \mathbf{q_E}(\theta), \theta\right) - C_I - \psi(\mathbf{e_N}, \mathbf{e_S}) - \sum_{\ell=1}^{n} c_E^\ell q_E^\ell\right] - \tilde{\lambda} U_C - \tilde{\lambda}\Pi_E\right\}$$
$$g(\theta) + \mu(\theta) V_\theta\left(\mathbf{q_I}(\theta), \mathbf{q_E}(\theta), \theta\right)$$

As in equilibrium the identity $\Pi_E \equiv 0$ is accomplished, the above expression boils down to

$$H = \left\{\left(1+\tilde{\lambda}\right)\left[V\left(\mathbf{q_I}(\theta), \mathbf{q_E}(\theta), \theta\right) - C_I - \psi(\mathbf{e_N}, \mathbf{e_S}) - \sum_{\ell=1}^{n} c_E^\ell q_E^\ell\right] - \tilde{\lambda} U_C\right\}$$
$$g(\theta) + \mu(\theta) V_\theta\left(\mathbf{q_I}(\theta), \mathbf{q_E}(\theta), \theta\right) \qquad (62)$$

The first order conditions of this optimization program are given by

$$\frac{\partial H}{\partial U_C} = -\dot{\mu}(\theta) \qquad \frac{\partial \dot{H}}{\partial q_I^\ell} = \frac{\partial H}{\partial q_E^\ell} = 0 \qquad \frac{\partial H}{\partial e_N} = \frac{\partial H}{\partial e_S} = 0$$

Regarding to the first one, we find that the transversality condition implies that $\mu(\theta) = 0$; therefore, we have that $\mu(\theta) = -\tilde{\lambda}(1 - G(\theta))$. With respect to the units of transportation service we get,

$$\frac{\partial V(\bullet)}{\partial q_I^\ell} - \frac{\partial C_I}{\partial q_I^\ell} = u_I^\ell(\bullet) - c_N^\ell - c_S^\ell = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{\partial V_\theta(\bullet)}{\partial q_I^\ell} \frac{1 - G(\theta)}{g(\theta)} \qquad (63)$$

$$\frac{\partial V(\bullet)}{\partial q_E^\ell} - \frac{\partial C_I}{\partial q_E^\ell} = u_E^\ell(\bullet) - c_N^\ell - c_E^\ell = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{\partial V_\theta(\bullet)}{\partial q_E^\ell} \frac{1 - G(\theta)}{g(\theta)} \qquad (64)$$

Applying the fact that $c_N^\ell = \delta_N^\ell s^\ell + c_N^{\ell+1} = \delta_N^\ell s^\ell + \delta_N^{\ell+1} s^{\ell+1} + c_N^{\ell+2} = \cdots = \sum_{k=\ell}^{n} \delta_N^k s^k$ and the integrability condition of the gross consumers' surplus, (66)-(67) can be rewritten as

$$\upsilon_I\left(Q_I^\ell,\theta\right) - \delta_N^\ell - \delta_S^\ell = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{\partial \upsilon_I\left(Q_I^\ell,\theta\right)}{\partial\theta} \frac{1-G(\theta)}{g(\theta)} \quad \forall \ell = 1,\ldots,n \tag{65a}$$

$$\upsilon_E\left(Q_E^\ell,\theta\right) - \delta_N^\ell - \delta_E^\ell = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{\partial \upsilon_E\left(Q_E^\ell,\theta\right)}{\partial\theta} \frac{1-G(\theta)}{g(\theta)} \quad \forall \ell = 1,\ldots,n \tag{65b}$$

In the simple case of a multiplicative taste parameter where $V(\mathbf{q}_I(\theta), \mathbf{q}_E(\theta), \theta) = \theta V(\mathbf{q}_I(\theta), \mathbf{q}_E(\theta))$ (65a) and (65b) boils down to a standard inverse elasticity rule (*see* Laffont and Tirole (2000) for more details).

$$\frac{p_I^\ell - \delta_N^\ell - \delta_S^\ell}{p_I^\ell} = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{1-G(\theta)}{\theta g(\theta)} \quad \forall \ell = 1,\ldots,n \tag{66a}$$

$$\frac{p_E^\ell - \delta_N^\ell - \delta_E^\ell}{p_E^\ell} = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{1-G(\theta)}{\theta g(\theta)} \quad \forall \ell = 1,\ldots,n \tag{66b}$$

As it can be seen, each reliability contract has a different incremental cost. Additionally, the price paid by the customer who values more reliability, θ is equal to the incremental cost of providing the gas in the wholesale market ("no distortion at the top"). It is also shown that for every reliability contract, the tariff schedule is increasing and concave; and as we mentioned before, this fact allow to implement the optimal allocation through a menu of two-part tariffs (*See* more in section VI).

On the other hand, with respect to the access charge the only way to preserve this discrimination principle in the wholesale gas market consists on the designing of discriminatory access charges for each reliability contract

$$a_E^\ell = \delta_N^\ell + \delta_E^\ell + \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{p_E^\ell}{\theta} \frac{1-G(\theta)}{g(\theta)} \quad \forall \ell = 1,\ldots,n$$

This means, that depending of the reliability contracts that the entrant is willing to serve in the wholesale market, he should be charged in such a way that is consistent with (66b).

Finally, to obtain the optimal tariff schedule, the optimization of the consumer program gives

$$\frac{\partial T_I(\mathbf{q}_I(\theta))}{\partial q_I^\ell} = \frac{\partial V(\bullet)}{\partial q_I^\ell} = \sum_{k=\ell}^{n} s^k \upsilon_I(Q_I^k,\theta) \quad \text{and} \quad \frac{\partial T_E(\mathbf{q}_E(\theta))}{\partial q_E^\ell} = \frac{\partial V(\bullet)}{\partial q_E^\ell} = \sum_{k=\ell}^{n} s^k \upsilon_E(Q_E^k,\theta)$$

Up to this moment we have expressed the optimality conditions in such a way that it is possible to measure the effects of the reliabilities on the optima tariff structure. However, it results vital to also express those conditions in terms of the volume of the customer's purchase. Consequently, we start by rephrasing the gross consumers' surplus as a function of the cumulates Q_I^ℓ and Q_E^ℓ,

$$V(\mathbf{q}_I(\theta),\mathbf{q}_E(\theta),\theta) = \sum_{j=I,E}\sum_{\ell=1}^{n}\int_0^{q_j^\ell} r^\ell \frac{\partial V_j(Q_j^{\ell-1}+x_j,\theta)}{\partial x_j}dx_j = \sum_{j=I,E}\sum_{\ell=1}^{n}\int_0^{q_j^\ell} r^\ell dV_j(Q_j^{\ell-1}+x_j,\theta)$$

$$V(\mathbf{Q}_I(\theta),\mathbf{Q}_E(\theta),\theta) = \sum_{j=I,E}\sum_{\ell=1}^{n} r^\ell\left(V_j(Q_j^\ell,\theta) - V_j(Q_j^{\ell-1},\theta)\right) \quad \text{and then,}$$

$$\frac{\partial V(\mathbf{Q}_I(\theta),\mathbf{Q}_E(\theta),\theta)}{\partial Q_j^\ell} = s^\ell \upsilon_j(Q_j^\ell,\theta)$$

Therefore the nonlinear tariff as function of the cumulates is given by,

$$\frac{\partial T_j(\mathbf{Q}_j(\theta))}{\partial Q_j^\ell} = s^\ell \upsilon_j(Q_j^\ell,\theta) = p_j^\ell(q_j) - p_j^{\ell+1}(q_j) \tag{67}$$

$$T_j(\mathbf{Q}_j(\theta)) = \sum_{\ell=1}^{n} s^\ell \int_0^{Q_j^\ell} \upsilon_j(x_j,\theta^\ell(x_j))dx_j \tag{68}$$

As Wilson (1993) states, the important feature of these conditions is that they can be solved for each contract separately as a function of the cumulatives, thus eliminating the dependence among contracts (however $\frac{\tilde{\lambda}}{1+\tilde{\lambda}}$ has to be the same for all the reliability contracts)[39].

39 Some application of this structure in the case of $\upsilon_j(x_j,\theta) = \theta - x_j$ and q uniformly distributed over [0,1] yields after some computations that

$$T_I(\mathbf{Q}_I(\theta)) = \frac{1}{1+\tilde{\phi}}\sum_{\ell=1}^{n}(c_N^\ell + c_S^\ell)q_I^\ell + \frac{\tilde{\phi}}{1+\tilde{\phi}}\sum_{\ell=1}^{n} r^\ell q_I^\ell\left(1-\frac{1}{2}\left[Q_I^\ell - Q_I^{\ell-1}\right]\right)$$

$$T_E(\mathbf{Q}_E(\theta)) = \frac{1}{1+\tilde{\phi}}\sum_{\ell=1}^{n}(c_N^\ell + c_E^\ell)q_E^\ell + \frac{\tilde{\phi}}{1+\tilde{\phi}}\sum_{\ell=1}^{n} r^\ell q_E^\ell\left(1-\frac{1}{2}\left[Q_E^\ell - Q_E^{\ell-1}\right]\right) \text{ where } \tilde{\phi} = \frac{\tilde{\lambda}}{1+\tilde{\lambda}}$$

This represents that the optimal tariff structure is not only cost-based (first term) but also demand-based (second term). And the demand criteria is in function of both reliabilities (discrimination following customers' heterogeneity) and cumulates (quantity discounts).

At last, the solution with respect to the reducing-cost effort of the gas utility yield,

$$\psi'(e_N, e_S) = -\frac{\partial C_N^0(\bullet)}{\partial e_N^0} \tag{69}$$

which represents the traditional cost reimbursement rule for the gas utility where the marginal disutility in reducing the fixed cost associated to the pipeline is equalized to the marginal cost reduction in this division of the gas utility.

VIII. MODEL 5: "EFFICIENT COMPONENT PRICING RULE"

Adhering to Armstrong, Doyle and Vickers (1996), there is another way to analyze the rationality of access prices based on the concept of opportunity cost. This idea was formalized by Baumol (1983) and Baumol-Sidak (1994, Ch. 7). In general the ECPR rule says that the access price should be set equal to the direct incremental cost of access plus the opportunity cost (e.g. lost profit from) supplying it. Although in its origins, the ECPR results in a intuitive margin rule, we want to analyze the concept of opportunity cost under various assumptions about demand and supply conditions. Additionally, we assume that p_I and are going to be fixed by the regulator.

In this case, it is necessary to suppose that the entrant's price is always set equal to marginal cost. This result comes from the first best solution to the entrant profit maximizing behavior represented by

$$\underset{q_E}{\text{Max}} \quad \Pi_E = (p_E - c_E - a)q_E \quad \text{which gives as a solution } p_E^* = c_E + a$$

This postulation is equivalent to Laffont-Tirole (1994) idea of constant returns to scale in the entrant's technology. Likewise, the incumbent and entrant's demand are imperfect substitutes. They accomplish the conditions of symmetry of the Slutsky matrix, which can be represented by

$$\frac{\partial x_I(p_I, p_E)}{\partial p_E} \equiv \frac{\partial x_E(p_I, p_E)}{\partial p_I} \geq 0$$

On the other hand, by Envelope theorem we have that $\frac{\partial \Pi_E}{\partial p_E} = q_E(p_E, a, c_E)$ and by Sheppard's Lemma $\frac{\partial \Pi_E}{\partial a} = -q_A(q_E, a, c_E)$. In this sense, $p_E^*(p_I, a, c_E)$ is such that

$$q_E(p_E^*(p_I, a, c_E), a, c_E) \equiv x_E(p_I, p_E^*(p_I, a, c_E))$$

These statements bring in the need to redefine the Pipeline's Operator Utility Level; so as to express it in terms of the new control variables,

$$U_I(p_I,a) = p_I q_I^*(p_I,a) + a q_A^*(p_I,a) - C_N\left(\beta, e_N, q_I^*(p_I,a) + q_A^*(p_I,a)\right)$$
$$- C_S\left(\beta, e_S, q_I^*(p_I,a)\right) \qquad (70)$$

Where $q_I^*(p_I,a) \equiv x_I^*(p_I,a)$ corresponds to optimal demand function met by the gas utility, which is derived from $q_I\left(p_I, p_E^*(p_I,a,c_E)\right)$. Besides, $q_A^*(p_I,a) \equiv q_E^*(p_I,a) \equiv x_E^*(p_I,a)$ represents the equilibrium supply and demand of access. Taking this into account, the maximization of social welfare can be represented as:

$$\text{Max} \quad W(p_I,a) = U_C + U_I(p_I,a) + \Pi_E\left(p_E^*,a,c\right)$$
$$\text{s.t.} \quad U_I \geq 0 \qquad \left(\tilde{\lambda}\right)$$

Where the entrants breakeven constraint[40] is ignored due to the assumption that they are pricing at the marginal cost. We let $\tilde{\lambda} \geq 0$ be the endogenous shadow price of the constraint over the profits of the incumbent. In this way, we have that the first order conditions of this problem with respect to p_I and are the following

$$(p_I) \quad \frac{\tilde{\lambda}}{1+\tilde{\lambda}} x_I^* = -\left(p_I - C_{NQ} - C_{Sx_I}\right)\frac{\partial x_I^*}{\partial p_I} - \left(a - C_{NQ}\right)\frac{\partial q_A^*}{\partial p_I} \qquad (71)$$

$$(a) \quad \frac{\tilde{\lambda}}{1+\tilde{\lambda}} q_A^* = -\left(p_I - C_{NQ} - C_{Sx_I}\right)\frac{\partial x_I^*}{\partial a} - \left(a - C_{NQ}\right)\frac{\partial q_A^*}{\partial a} \qquad (72)$$

In this case, the first best would have achieved productive and allocative efficiency. However, given the breakeven constraint, it is impossible to meet these conditions together. And given $p_I > C_{NQ} + C_{Sx_I}$ we have that access is priced above marginal cost and can be represented as:

$$a = C_{NQ} + \left(p_I - C_{NQ} - C_{Sx_I}\right)\left(-\frac{\frac{\partial x_I^*}{\partial a}}{\frac{\partial q_A^*}{\partial a}}\right) + \frac{\tilde{\lambda}}{1+\tilde{\lambda}}\left(-\frac{q_A^*}{\frac{\partial q_A^*}{\partial a}}\right)$$

40 In the presence of fixed costs for the entrants, this constraint also represents the fixed-cost recovery constraint.

If we assume that $-\frac{\partial x_I^*}{\partial a} \Big/ \frac{\partial q_A^*}{\partial a} = \sigma$ we get

$$a = C_{NQ} + \sigma\left(p_I - C_{NQ} - C_{Sx_I}\right) + \frac{\tilde{\lambda}}{1+\tilde{\lambda}}\left(-\frac{q_A^*}{\frac{\partial q_A^*}{\partial a}}\right) \tag{73}$$

where σ can be interpreted as the displacement ratio, in the terminology of Armstrong, Doyle and Vickers (1996). It roughly measures the reduction in the demand for the incumbent's product originated by providing additional units of access to the entrants.

A. Input Substitution: Storage and Transportation Unbundling

Unbundling pipelines gives natural gas storage a new role in natural gas and transportation markets in addition to its traditional role of load balancing. In this possible structure, storage operators become active in the gas market, buying and selling natural gas as market conditions change. Storage can be crucial in relieving pipeline congestion in local gas markets and helping to lower gas prices.

A storage operator can use the available pipeline capacity in off-peak periods, when natural gas prices are low, to inject natural gas into storage, and then sell this gas in the local market for higher prices during peak periods. The storage operator gather the benefits of high peak prices, but it also pushes peak prices toward competitive levels because the availability of natural gas from storage relieves congestion, at least partially. And its high profits will attract additional storage facilities to the market, which will further lower prices.

In this case, we consider a storage operator as a new supplier in the transportation market, and we will show, based on the above results that the implementation of this policy helps to lower the access charge in the transportation market.

$$\sigma = \sigma_d \times \sigma_s = \left(-\frac{\partial x_I^* / \partial p_E}{\partial q_E^* / \partial p_E}\right)\left(\frac{\partial q_E^* / \partial a}{\partial q_A^* / \partial a}\right)$$

where σ_s represents the supply-side substitution possibilities. As we have assumed along this document, when they are not present, then $q_A^* \equiv q_E^*$ and $\sigma_s = 1$. Additionally, if we take account of

$q_A^*(p_I, a) \equiv q_A\left(x_E^*(p_I, a), a\right) \equiv q_A\left(q_E\left(p_E^*(p_I, a), a\right), a\right)$ and,

$$\frac{\partial q_A^*(p_I,a)}{\partial a} \equiv \frac{\partial q_A(\bullet)}{\partial q_E}\frac{\partial x_E^*(\bullet)}{\partial a} + \frac{\partial q_A(\bullet)}{\partial a}$$

we get that $\sigma_s = \dfrac{\dfrac{\partial q_E^*}{\partial a}}{\dfrac{\partial q_A}{\partial q_E}\dfrac{\partial x_E^*}{\partial a} + \dfrac{\partial q_A}{\partial a}} = \dfrac{1}{\dfrac{\partial q_A}{\partial q_E} + \left(\dfrac{\partial q_A}{\partial a} \Big/ \dfrac{\partial q_E^*}{\partial a}\right)}$

The ability to substitute transported gas by stored gas is represented by $\frac{\partial q_A}{\partial a}$. So, an increase in the absolute value of this partial derivative implies a reduction in the value of σ. Therefore, based on (73) we can sustain that the introduction of separated storage operators determines a reduction in the access price charge by the gas utility to entrants in the downstream sector.

B. ECPR and Ramsey Pricing

Under the initial assumptions of fixed proportions technology, homogeneous product and no possibilities of bypass we get that $\sigma = 1$[41]; and if we ignore the breakeven constraint for the incumbent ($\tilde{\lambda} = 0$) we will obtain

$$a = C_{NQ} + (p_I - C_{NQ} - C_{Sx_I}) \tag{74}$$

This corresponds to the traditional ECPR formula where the first term of the right represents the direct cost of providing access and the second justifies the existence of an opportunity cost of doing so, given by the incumbent's lost marginal profit. However, our interests are focused to the case which the breakeven constraint is relevant for the pipeline operator. This implies that when the access charge and the wholesale price are chosen optimally, the access charge should be greater that the applied by the ECPR (adding a Ramsey term involving elasticities of demand).

Finally, it is important to show the way that ECPR approximates to Laffont-Tirole approach of Ramsey pricing. In this way, we should express conditions (71) and (72) in terms of for p_E and p_I, using the identities $q_A = q_E$, $q_I^* = x_I^*$ and $p_E^* = a + c_E$. This yields,

$$p_I = -\frac{\tilde{\lambda}}{1+\tilde{\lambda}}\frac{\partial p_I}{\partial x_I^*}\frac{x_I^*}{p_I}\frac{\boldsymbol{p_I}}{\boldsymbol{p_I}} + C_{NQ} + C_{Sx_I} + (a - C_{NQ})\left(-\frac{\partial q_A^*}{\partial p_I}\frac{\partial p_I}{\partial x_I^*}\right)$$

41 $q_A^* = Q - x_I^* = Q - q_I^*$. Therefore, $\frac{\partial q_A^*}{\partial a} = -\frac{\partial x_I^*}{\partial a}$

$$p_I = -\frac{\tilde{\lambda}}{1+\tilde{\lambda}}\frac{p_I}{\eta_I} + \left(C_{NQ} + C_{Sx_I}\right) + \left(p_E - c_E - C_{NQ}\right)\left(-\frac{\partial q_E^*}{\partial p_I}\frac{\partial p_I}{\partial q_I^*}\right) \tag{75}$$

$$a = -\frac{\tilde{\lambda}}{1+\tilde{\lambda}}\frac{\partial p_E}{\partial q_E^*}\frac{q_E^*}{} \frac{p_E}{p_E} + C_{NQ} + \left(p_I - C_{NQ} - C_{Sx_I}\right)\left(-\frac{\partial x_I^*}{\partial p_E}\frac{\partial p_E}{\partial q_E^*}\right)$$

$$p_E = -\frac{\tilde{\lambda}}{1+\tilde{\lambda}}\frac{p_E}{\eta_E} + \left(C_{NQ} + c_E\right) + \left(p_I - C_{NQ} - C_{Sx_I}\right)\left(-\frac{\partial q_I^*}{\partial p_E}\frac{\partial p_E}{\partial q_E^*}\right) \tag{76}$$

This gives a system of equations which after being solved and taking into account the fact that,

$$\hat{\eta}_I = \eta_I \frac{1 - \frac{\partial q_I^*}{\partial p_E}\frac{\partial p_E}{\partial q_E^*}\frac{\partial q_E^*}{\partial p_I}\frac{\partial p_I}{\partial q_I^*}}{1 - \frac{p_E}{p_I}\frac{\partial q_I^*}{\partial p_E}\frac{\partial p_I}{\partial q_I^*}\frac{\eta_I}{\eta_E}} \quad \text{and} \quad \hat{\eta}_E = \eta_E \frac{1 - \frac{\partial q_I^*}{\partial p_E}\frac{\partial p_E}{\partial q_E^*}\frac{\partial q_E^*}{\partial p_I}\frac{\partial p_I}{\partial q_I^*}}{1 - \frac{p_I}{p_E}\frac{\partial q_I^*}{\partial p_E}\frac{\partial p_E}{\partial q_E^*}\frac{\eta_E}{\eta_I}}$$

and brings the same result of the perfect information case of Laffont-Tirole approach (Equations 8 - 9).

IX. CONCLUSIONS

In this document we have applied the general literature of access pricing which has been widely developed in the telecommunication and electricity sectors. It is common that the various tariff schedules try to take advantage of the opportunities of price discrimination, that can be reached in different frameworks. However, the most common in this circumstances (as it is signaled by Boyer (1997)) is the Ramsey structure of third degree price discrimination. From this point of view the access charges have to be not only cost-based but also demand-based. This implies that this prices should reflect the possibilities of substituability between the gas utility service and the one from its competitors in the wholesale trading and supply market.

However, this Ramsey benchmark can be extended to the multiproduct structure that accommodates perfectly to the nature of the pipeline transportation service. Although, it is difficult to obtain a simple measurement of the cross effects between the demand for the differentiated services offered by the gas utility, and between them and the ones offered by the entrants. As a consequence, we have supposed that the demand of the variety of services offered by both the entrants and the gas utility are independent. So, the access charges will only reflect the characteristics of the substituability of the final service offered by the different participants of the market.

Under the same structure, the possibility of peaks in demand that make binding the capacity constraints led us to apply a simple structure of peak-load pricing to the gas sector in both the symmetric and asymmetric information environments. As it is traditional, we obtained that the access tariff in the case of peaks on demand should be fixed higher than in the idle capacity periods, owing to the cost of expanding capacity to satisfy the demand requirements.

After doing so, we introduced the principles of nonlinear pricing to this multiproduct structure to show the effect of the technological substituability boundaries in the self-selection constraints and implicitly in the optimal tariff schedule. There we show the way the regulator manages the interest of non-firm contractors of mimicking being captive customers to increase the profit making opportunities in the unavoidable secondary market. Alternatively we made a remark on the fact that the structure of section 6 does not take into account the behavior of the marginal cost with respect to the provision of reliability.

To solve this problem, we designed a tariff structure that assumes that the 'incremental cost' is increasing with respect to the level of reliabilities (it is less costly to serve low reliability contracts), taking as a base the methodology of Wilson (1993; Ch. 13). Under this assumptions we could obtain a tariff structure which assigns prices simultaneously to increments in quantities and reliability.

Finally, we make use of the Efficient Component Pricing Rule to design optimal access charges, due to its empirical relevance. Under this framework, we show in section 8 that the unbundling of transportation and storage helps to reduce the monopoly distortions over the access prices. In addition to this we conciliated (under some restrictive optimality conditions) the ECPR and the Ramsey pricing setting of gas transportation services.

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