PRICING NATURAL GAS DISTRIBUTION IN MEXICO*

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ABSTRACT

We examine regulation of distribution tariffs in the Mexican natural gas industry. Average revenue in each period is constrained not to exceed an upper bound and is calculated as the ratio of total revenue to output in the current period. This regime implies incentives for setting two-part tariffs strategically. The usage charge is typically dropped to its lowest feasible level while the fixed charge is raised to compensate for the loss of profit. The regime also creates a stochastic effect that implies decreased values of consumer surplus for lower levels of risk aversion and uncertainty.

Keywords: average-revenue regulation, risk and uncertainty, stochastic dynamic programming, natural gas distribution.

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1. Introduction[**]

Most prominent among incentive regulatory schemes are the “price cap” regimes which place an upper bound over an index of the regulated firm’s prices so that the firm has incentives to reduce production costs and to innovate. Average-revenue regulation is a price-cap regime that sets an upper limit on revenues per unit and has been the preferred way of regulating prices of firms whose costs are dependent on total product and whose products are commensurable.[1] It renders more flexibility than tariff-basket regulation because it does not establish weights that limit variation among relative prices.[2] Vogelsang (2001) argues that average revenue regulation can also be interpreted as a case of price-cap regulation where the different economic goods or services are lumped together under the same weight.

The economics literature shows that, under stable cost and demand functions or under myopic profit maximization, average-revenue regulation induces inefficient pricing, restricts the range of market coverage, and promotes strategic nonlinear pricing by the firm. The consequence is reductions in consumer surplus with respect to consumer surplus implied by other price-cap regimes such as tariff-basket regulation. More specifically, Bradley and Price (1991) show in a

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[1] Goods produced by a multiproduct firm are said to be commensurable if they are produced with a technology characterized by:

$$C(Q_1,....,Q_n) = C(\sum_i Q_i)$$

where C is the cost function and Q_i is the ith product for i=1,2,...,n. For noncommensurable goods, there are problems in defining average revenue because total revenue has to be divided by a single type of quantity unit. As Vogelsang (1999) argues, the use of kWh in electricity transmission hides differences in voltage levels, reliability, time of day, location, etc.

[2] Tariff-basket regulation is another price-cap regime that is based on weights for the prices of different products such that a cap is set over an index $I(p) = \sum_{i=1}^{n} w_i p_i$, where p_i are prices, and w_i are weights that might be quantities of the previous year (chained *Laspeyres* index), quantities of the current period (*Paasche* weights), weights fixed over time (fixed *Laspeyres* weights), and projected quantities (*Idealized* weights). Tariff-basket regulation is extensively used in the telecommunications industry.

static model that the prices charged by a monopolist under the average-revenue constraint significantly differ from Ramsey prices, and that the range of the market covered is less than the range that would be covered under no restrictions at all or the range under the Ramsey program. They also show that tariff-basket regulation is superior to the average-revenue methodology but conclude that the latter regulation is a softer restriction for the firm than the former one. Law (1995 b) extends this analysis and demonstrates that consumer surplus may decrease when the average-revenue cap becomes more stringent. Sappington and Sibley (1992) study the intertemporal strategic effects of two-part tariffs subject to the average-revenue constraint under cost and demand stability. They prove that by setting the usage charge at a low level the average-revenue restriction is relaxed in future periods and thus allows the firm to increase future prices. This means that the firm has incentives to set its nonlinear tariffs strategically so that both consumers' surplus and total surplus might be lowered. Sappington and Sibley show that alternative price-cap plans, such as maximum average revenue calculated with a fixed output level, eliminate incentives for strategic pricing. [3]

These results do not leave any doubt regarding the inefficiencies associated with average-revenue regulation under stable (static or dynamic) environments. Notwithstanding, the Mexican Energy Regulatory Commission (CRE) uses the average revenue regime in order to regulate the initial development stages of distribution projects in the natural gas industry, characterized by volatile cost and demand conditions.[4] Under the CRE's plan, average revenue is computed each year using the current period throughput, and not exceeding a predetermined cap. A practical problem in implementing this method is that prices must be set at the start of the year, but throughput is not known until the end of the year. Therefore, the regulated firm must forecast

[3] Sappington and Sibley (1992) reach this conclusion for the FCC's plan to regulate ATT.
[4] Under such a scenario the conditions for commensurable goods presented in footnote 1 do not hold.

volume at the beginning of the year and the regulator must apply a correction factor at the end of the year so as to adjust for estimation errors.

In this paper we develop a stylized approximation of the CRE's price-cap plan. By studying this very specific topic we also address the more general issue of the effects of average-revenue regulation on consumer surplus under a stochastic demand function, and myopic profit maximization. This is an effort to contribute to the literature of regulation under risk and uncertainty where non-linear price indexes change over time.[5] We show that the CRE's average-revenue constraint provides incentives for the regulated firm to engage in strategic nonlinear pricing. By setting a low usage charge in a certain period, the firm can exchange the current period's increase of the fixed charge to a posterior period.

Additionally, the CRE's methodology implies the existence of another effect due to the random nature of demand forecasting that also affects the profit-maximizing behavior of the firm. This stochastic effect is such that as firm's risk aversion and uncertainty decrease consumer surplus diminishes with the implementation of average-revenue regulation. These results obtain through a numerical analysis applied to a model of stochastic dynamic programming using data from natural gas distribution projects in Mexico.

Our analysis proceeds as follows. In section 2, we describe the CRE's price-cap plan for distribution tariffs in the natural gas industry. In section 3, we present a model showing the strategic and stochastic effects of the CRE's regulatory plan. In section 4 we analyze solutions for three cases: static, dynamic with strategic pricing, and dynamic without strategic pricing. For this last case, we carry out in 4.3.1 and 4.3.2 a simulation exercise for the natural gas distribution projects of the winners of bidding processes completed so far by the CRE. This exercise studies

[5] Neu (1993), Fraser (1995), and Law (1995 a) study the effects of the chained Laspeyres restriction under a changing demand function, nonuniform cost changes, and myopic profit maximization, respectively.

the consequence of the stochastic effect on both profit maximization and consumer surplus. It also provides a careful analysis of the demand function for natural gas in Mexico and of the behavior of possible demand shocks. Results of the numerical analysis are shown in 4.3.3. Concluding remarks and suggestions for future research are presented in section 5.

2. The CRE plan

In this section, we describe the essential features of the CRE's complex price-cap plan to regulate natural gas distribution tariffs. We next list the main elements of the plan.

1 Price-cap regulation is in effect for review periods of five years. In each of these periods, the starting price cap is computed through a cost-of-service methodology.[6]

2 In each five-year period, inflation (*RPI*), efficiency (*X*), pass-through (*Y*), and correction (*K*) factors adjust the price-cap annually, at the end of the year.[7]

3 In the first five-year period, the initial value of the average-revenue cap is the one proposed by the winner of the distribution bidding contest which grants twelve years of exclusivity.[8]

4 The CRE uses average-revenue regulation during the first five-year regulatory period while a tariff-basket regime may be used later on.[9] The reason is that most natural gas

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[6] Cost of service reviews imply setting two part tariffs according to well defined methodologies on allocation of costs to charges, calculation of capacity fees, distribution rates by delivery pressure, interruptible service rates, and contract rates. Contract (nonregulated) arrangements are permitted as long as they are not used to evade regulation or to perform cross subsidies between the regulated and the nonregulated markets. See Comisión Reguladora de Energía (1996) chapter 9.

[7] The inflation index is a weighted average of the consumer price indices of Mexico and the United States, and incorporates corrections for fluctuations in the exchange rate. The CRE authorizes monthly or quarterly inflation adjustments under unusual high inflation or peso-devaluation scenarios. The efficiency factor will be equal to zero for the first five years of operation, and the passthrough factor includes costs that the firm can directly transfer to consumers (such as system balance gas costs and incremental costs due to change in the domestic tax regime).

[8] In each bidding contest, the CRE defines a distribution area and, based on equity criteria, sets a minimum consumer-coverage number that the firm must reach at the end of the first five years. Tender participants present their proposals with all the necessary technical and economic information on the project, including a market demand study. Evaluation is carried out by the CRE in two stages. In the first stage the technical quality of the project is evaluated. The winner is selected among the survivors of the first stage according to the lowest value of the average revenue for the first five-year period. Exclusivity includes distribution but not marketing.

distribution projects in Mexico are greenfield and thus characterized by greater cost and demand uncertainty at the beginning than in subsequent phases. Average-revenue regulation represents a laxer constraint to the firm than the tariff-basket constraint, and provides the firm with more flexibility to set its tariffs in a risky environment.[10] Likewise, tariff-basket regulation has been shown to induce firms to set prices that converge to (diverge from) the Ramsey structure under stable (changing) cost and demand functions, and myopic (non myopic) profit maximization.[11]

5 The firm calculates its average revenue at the initiation of each year using the current-period volume because, in most of the new Mexican distribution projects, there exists no previous history on distributed volumes. Since the real value of throughput is not known until the end of the year, the firm must set its prices at the start of the year based on the expected value of the volume for that year.[12] As, in general, the firm's forecast will not be accurate, the regulator must then adjust at the end of the year the next period's price cap with a correction factor.[13]

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[9] See Comisión Reguladora de Energía (1996), article 6.12.

[10] See Bradley and Price (1991), pp. 103-107.

[11] Under cost and demand stability, the use of the chained Laspeyres index implies a redistribution of social surplus that permits the firm to recover its long-run fixed costs and, at the same time, the intertemporal maximization of consumer surplus. On this, see Vogelsang (1989, 1999), Bertoletti and Poletti (1997), Loeb and Magat (1979), and Sibley (1989). Neu (1993) shows that under changing demand conditions, prices that are subject to the Laspeyres restriction can diverge more from the Ramsey structure than do cost-of-service prices. This would discourage the change from a rate-of-return regulatory regime to an incentive scheme. Fraser (1995) proves that under a nonuniform changing cost structure, prices under the Laspeyres restriction may not converge to Ramsey prices. Law (1995 a) and Sappington (1980) reach a similar conclusion for prices that result from maximizing discounted future profits.

[12] Firms forecast each year's volume based on the market study originally contained in their bidding proposal.

[13] The CRE requires two correction adjustments in the revenue yield cap:

- In the fourth year of service, based on the achieved revenues of the first three years of operation (plus interest), and
- In the sixth year, based on the achieved revenues of the fourth and fifth years of operation (plus interest). See Comisión Reguladora de Energía (1996), articles 6.55 through 6.63.

We abstract from this complication in our formal analysis of Section 3 and assume that the correction factor is applied in each year (without interest).

The CRE thus decided to combine in the initial five-year period the use of the average-revenue restriction with competition for the natural gas distribution market. This policy has been successful so far in attracting investment to the Mexican natural gas distribution projects.[14] However, a question remains regarding the possible effects of this combined policy on consumer surplus. We precisely analyze this issue in the next sections for the simple case where there is only one product. This simplification allows us to isolate the particular incentives for strategic nonlinear pricing and the effects of the random nature of the CRE's price-cap plan.

3. The Model

Our representation of the CRE's price-cap plan for a natural gas distribution firm is as follows. For each of T periods, the firm's average revenue in period $t = 1, \ldots T$ is constrained not to exceed a maximum average revenue M_t. (For the Mexican natural gas distribution projects, "periods" are years, and $T = 5$). Average revenue in year t is computed using the firm's sales in the current year, t. The general representation of the demand curve for the firm's product in each year is given by $Q(P_t,F_t)$, where P_t is the usage (or variable) charge levied in year t and F_t is the fixed charge (or "entry fee").[15] However, we abstract from income effects and hence assume that consumer demand is influenced only by the established usage charge and that consumers are inframarginal so that no consumers drop out when the fixed fee is increased. Thus, we will write $Q_t = Q(P_t)$. We further suppose that when demand is positive, it declines with an increase of the usage charge, i. e., $Q'(P) < 0$ for all P such that $Q(P) > 0$. We assume there is a fixed number of

[14] From 1995 through 2002, tenders' winners will invest around 1 billion dollars, and consumer coverage in distribution areas will grow from 572 thousand consumers to around 2 million consumers. See Rosellón and Halpern (2001).

[15] For several consumers, F_t can be better thought as the revenue from the fixed charge rather than the fixed charge itself. This precision could be important when (a) different consumers face different fixed charges, and (b) the number of consumers differs from period to period. We assume that the fixed charge is equal for all consumers.

consumers that individually have no perceivable influence on total demand and that know both usage and fixed charges since the start of the period.[16]

The calculated average revenue AR_t is known (both by the firm and the regulator) at the *end* (December) of year t and can be written as

$$AR_t = P_t + \frac{F_t}{Q_t}$$

The firm, however, has to choose its two-part tariff at the *beginning* (January) of year t according to its demand forecast, and in order to maximize the expected value of profits subject to the (Paasche-type) expected average-revenue restriction given by

$$E(AR_t) = P_t + \frac{F_t}{E(Q_t)} \leq M_t \tag{1}$$

where:

$E(AR_t)$ is the expected average revenue at the start of year t

$E(Q_t)$ is the expected value of demand at the start of year t

M_t is the allowed maximum average revenue in year t

This constraint can be rewritten as

$$F_t \leq E(Q_t)[M_t - P_t] \tag{2}$$

It is apparent from (2) that the average revenue constraint can be viewed as restricting the entry fee (F_t) in each period not to exceed the product of (i) the difference between the "cap"

[16] An alternative working assumption would be that the fixed fee(s) is (are) not known before the end of a period. In

(M_t) and the usage charge (P_t) in that period, and (ii) the expected value of throughput in the current period ($E(Q_t)$).

In December of year t, once the real value of demand Q_t is known, the regulator compares the achieved average revenue AR_t to the cap M_t. If $AR_t \neq M_t$ a correction factor K_t is added to M_t so as to form the allowed maximum average revenue of year $t + 1$:

$$M_{t+1} = K_t + M_t \qquad (3)$$

K_t will be positive, zero or negative whenever $AR_t < M_t$, $AR_t = M_t$, or $AR_t > M_t$, respectively. The initial value of the average-revenue yield cap M_0 is set at the beginning of the (five-year) regulatory and is the result of a bidding process. Then $M_t = M_0 + K_1 + \ldots + K_{t-1}$. We disregard other factors (such as inflation and efficiency factors) that may adjust the value of average revenue cap.

Now, what can make AR_t and M_t differ? Or, in other words, what are the effects that determine K_t? We next show that K_t is determined by two different kinds of effects: an intertemporal strategic effect and a stochastic effect. We first analyze the former effect.

As it is evident from (2), the firm can manipulate the determination of the usage charge in January of year t while maximizing expected profit subject to the expected average revenue constraint. The firm can reduce P_t so as to have a more relaxed regulatory restriction during year t + 1. In order to clearly explain this strategic effect, let us abstract from stochastic effects and assume for one moment that $E(Q_t) = Q_t$, for all t. A reduction in p_t implies increases in $[M_t - P_t]$ and Q_t. The firm can then strategically increase F_t so that $\Delta F_t < \Delta(Q_t[M_t - P_t])$

that case, consumers would also have to make decisions under uncertainty and anticipate the fixed fees. If it were which implies $AR_t < M_t$ and, hence, $K_t > 0$. The average-revenue restriction in period $t+1$ then becomes $F_{t+1} \leq Q_{t+1}\left(M_t + K_t - P_{t+1}\right)$. In other words, a lower usage charge in period t lets the firm set a higher fixed charge in period $t+1$.[17] This effect is very similar to the one described in Sappington and Sibley (1992) but the mechanics of transmission is slightly different.[18]

Let us now analyze the stochastic effect on K_t. Randomness in our model arises from the random nature of each year's process of demand forecasting by the firm. The firm has to make economic decisions in January while real demand is only known until December. We assume that it is improbable that real demand exactly coincides with forecasted demand due to uncertain external factors - such as macroeconomic conditions, national or international economic growth, financial crises, adverse political situations, natural phenomena - that might affect natural gas supply or demand. These factors are more likely to be present in developing economies such as the Mexican economy.[19] The randomness of the forecasting of Q_t translates into randomness of K_t. The stochastic effect on the determination of K_t is thus realized in December of each year, once the true value of demand is known and the achieved average revenue is compared to the allowed maximum average revenue. Since, in general, $E\left(Q_t\right) \neq Q_t$ we will have $AR_t \neq M_t$.

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further assumed that fixed fees do not influence the consumption decision, this uncertainty would not matter.

[17] In the extreme, the firm might drop the usage charge in a certain period to the lowest feasible level because consumer demand is inelastic with respect to the entry fee.

[18] Sappington and Sibley (1992) analyze a price-cap plan used by the US Federal Communication Commission (FCC). They show that two-part tariffs subject to the average-revenue constraint induce an intertemporal strategic conduct by the firm which results from the lagged quantities used to compute the average revenue. Producers choose to reduce their usage charge in period *t* in exchange for an increase in period *t*'s demand and, therefore, in period's *t+1* fixed charge. For certain values of the discount rate, this effect is such that both consumers' surplus and total surplus are reduced. However, the use of last period's quantities in the calculation of the average revenue avoids the problem of unknown quantities and ex post adjustments.

[19] A very cold winter in the northeast of the USA during 1996-1997 caused a 135% increase in the natural-gas price in Mexico. During the winter of 2000-2001, larger increases in gas prices were also experienced influenced by increased power demand, and by low natural gas storage levels in the United States. The price of natural gas and the price of liquid petroleum gas are set in Mexico by using reference prices in southeast Texas (see Rosellón and Halpern (2001), pp. 11-14, and Brito, Littlejohn and Rosellón (2000)).

Thus, the correction factor K_t will have to be added to M_t to arrive at M_{t+1} and this will happen with an over time changing probability.

Our problem consists of analyzing how the correction factor may influence the outcomes of a price-cap plan based on average-revenue regulation. To explore this issue, it is necessary to examine the solution to the following problem:

$$\max_{p_t, E_t} E\left\{\sum_{t=1}^{T} B^t \left(P_t Q_t - C(Q_t) + F_t\right)\right\}$$

subject to (4)

$$Q_{t+1} = Q_t(P_t) - K_t$$

$$F_t \leq E\{Q_t[M_t - P_t]\}$$

$$Q_T \geq N$$

$$B^t \in [0,1]$$

System (4) is a stochastic dynamic program composed of a *risk-sensitive* functional, a transition equation, an average-revenue restriction, and a final condition on Q_t. The functional, which expresses the expected value of the profit flow of a monopolist, includes a discount factor $B \in (0,1]$, two controls, F_t and P_t, a state variable Q_t, and a cost function $C(Q)$.

The state variable Q_t is assumed to be cumulative. The regulator requires in the bidding package that accumulated demand along the planning horizon of *T* years be at least equal to *N* volume units. The firm will thus calculate its demand in year *t* such that the sum of the each year's covered demands is equal to N at the end of T years ($Q_T \geq N$).[20] In absence of forecast errors, so that K_t equals zero for each t, the N volume units will be reached in a uniform way (equal amounts of aggregated demand in each year), while if K randomly gets non-zero values in each year N will be reached in a non-uniform way (different amounts of aggregated demand each year).

The transition equation $Q_{t+1} = Q_t(p_t) - K_t$ is a first-order stochastic difference equation thus expressing that period $t+1$'s demand is equal to the demand accumulated until period t minus the correction factor K_t. Whenever there is no stochastic effect, aggregated demand will be exactly equal in each year (say to Q_0) and hence final demand Q_T will be equal to the sum of these equal demands ($Q_T = TQ_0 = N$). This would be equivalent to modeling a situation where the firm connects in date 0 the fixed amount of consumers required by the regulator and the consumers' aggregated demand is equal in each year. [21]

Correction factor K_t appears with a negative sign in the stochastic transition equation because whenever $K_t > 0$ the average-revenue restriction in period $t+1$ will be relaxed. The firm will set P_{t+1} and F_{t+1} according to the increase in K_t while, in January of year $t+1$, it maximizes expected profits subject to the expected average-revenue constraint $F_{t+1} \leq E(Q_{t+1})(M_t + K_t - p_{t+1})$. When the fixed charge F_{t+1} is not varied the firm will typically increase p_{t+1} implying a decrease in demand Q_{t+1}.

4. Solution

[20] We use demand coverage as a proxy for consumer coverage. The CRE only cares in the bidding package about the number of consumers (not for the amount of demand) covered at the end of the first five years. However, the firm acquires in its bid proposal the compromise of covering X consumers that will demand N volume units at the end of those five years.

[21] In real world, however, the firm gradually connects consumers until it covers the number required by the CRE. Under lack of uncertainty, the firm satisfies in each year the same amount of demand from previous-year consumers

4.1 Case 1: Static Scenario

Let us first analyze the first very simple case where there is only one period and no uncertainty. Suppose that both the firm and the regulator agree that the demand function is of the form $Q = a - bP + \upsilon \ \forall P \leq \frac{a}{b}$, or $Q = 0 \ \forall P \geq \frac{a}{b}$, where a and b are positive constants and υ is a random variable with E(υ) = 0. Suppose that the cost function is linear of the form $f + cP$ where f [fixed costs] and c [marginal cost] are positive constants. The firm is required to choose its fixed fee, F, and the usage charge, P, at the start of the period to satisfy:

$$P + \frac{F}{a - bP} \leq M \tag{1'}$$

which is essentially equation (1) under the static and certain conditions. The firm maximizes expected profits by choosing p and F subject to constraint (1') and the cumulative constraint $Q \geq N$. Expected profits are $F + (P - c)(a - bP) - f$. The constraint, which binds, is $F = (M - P)(a - bP)$. Substituting this last expression into the expected profit function gives expected profits equal to $(M - c)(a - bP) - f$. The firm will only produce at all if $M > c$ (otherwise neither variable nor fixed costs can be covered). Expected profits are thus a negative linear function of the usage charge P. The price P should be dropped to the lowest feasible level (perhaps 0), or to the level that just ensures that consumers are just willing to participate. Intuitively, by cutting P the firm is able to raise output, and each extra unit of sales generates constant profit of $M - c > 0$ since the firm can raise F to more than compensate for the lost operating profit. That is, F would operate as a lump-sum tax. Thus the solution to the optimization problem is to set P close to 0 and F equal to the level that satisfies the average-revenue and cumulative constraints.

4.2 Case 2: Dynamic Scenario with Strategic Pricing

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plus the additional demand from new connected consumers. This situation is equivalent to a model where all

Let us now assume several periods and $\upsilon_t > 0$ for a certain period t. The firm will then simply cut F_{t+1} in period $t+1$, while keeping P_t close to 0. That is the fixed cost is strategically set so as to bear all the burden of misprediction.

4.3 Case 3: Dynamic Scenario with no Strategic Pricing

Assume there is no strategic effect so that $F_t \leq E(Q_t)[M_t - P_t]$ is strictly binding, for all t. Let us then concentrate our analysis on the stochastic effects that determine the value of K_t. In such a case the solution would be equivalent to applying in each period the static-case solution. For each t, the usage charge P_t is nearby 0 and the fixed charge F_t is varied in each period so as to maximize expected profits, to compensate for the variations in the average-revenue constraint due to the random behavior of the correction factor K, and to comply with the cumulative constraint $Q_T \geq N$.

However, we proceed to isolate how the stochastic effect alone may affect consumer surplus. For that purpose, we assume that the fixed fee is kept constant in each period and study the way the firm manipulates the usage charge each period in order to maximize its expected profits, subject to the average-revenue and cumulative constraints, and under the stochastic behavior of the correction factor K. Assuming linear demand and cost functions system (4) becomes:

$$\max_{P_t} E\left\{\sum_{t=1}^{T} B^t \left(M_t\left[a - bP_t\right] - \left[f + cP_t\right]\right)\right\}$$

subject to (5)

$$Q_{t+1} = a - bP_t - K_t$$

$$Q_T \geq N$$

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consumers are connected since date 0, and demand is uniformly covered each year.

Note that, in this new system, the usage charge appears as the only control variable and, therefore, we can focus our attention on the stochastic effects of K_t over the determination of the optimal P_t. We next characterize the solution to system (5).

4.3.1. Determination of Optimal Controls

The usual procedure to find the *control law* or *policy* $\pi = \left\{P_{1,...,}P_T\right\}$ associated with a system such as (5) starts by defining the following elements of the dynamic-programming reference framework (Bertsekas 1976):

$g_T(Q_T) = B^T[G(N)]$, where G are the monopolist's net profits (6.1)

$$g_t(Q_t, P_t(Q_t), K_t) = B^t[M_t(a - bP_t) - (f + cP_t)] \tag{6.2}$$

$$Q_{t+1} = \varphi_t(Q_t, P_t(Q_t), K_t) = a - bP_t - K_t \tag{6.3}$$

$$P_t(Q_t) = [0, \alpha) \ \forall \alpha \in R^+ \tag{6.4}$$

Expression (6.1) indicates that profits in period *T* are realized when the accumulated amount of final demand covered by the monopolist is equal to *N* (or briefly $\sum_{t=0}^{T} Q_t = N$). This amount will be distributed among each of the *T* periods that integrate the planning horizon, and according to the set of optimal controls. Optimal demand allocated in each period will provide the producer with the highest discounted profit flow under conditions of uncertainty, as established in equations (6.2) and (6.3). The controls associated with demands make economic sense if and only if they are non-negative (6.4).

Once the reference framework has been settled, we now rewrite system (5) in terms of the Jacobian functions ($J_T\left(Q_T\right)$ in system (7)) and the *Bellman* equations for the k periods (equations (7.1), (7.2), and (7.3)), using the method of *backward induction*:

$$J_\pi\left(Q_0\right) = \max_{P_t} \underset{K_t}{E}\left\{g_T\left(Q_T\right) + \sum_{t=1}^{T-1} g_t\left(Q_t, P_t\left(Q_t\right), K_t\right)\right\}$$

subject to (7)

$$Q_{t+1} = \varphi_t\left(Q_t, P_t\left(Q_t\right), K_t\right) = a - bP_t - K_t$$

Period T

$$J_T\left(Q_T\right) = \max_{P_T \geq 0} \underset{K_T}{E} B^T\left\{M_t\left(a - bP_T\right) - \left(f + cP_T\right)\right\} \tag{7.1}$$

Períod T-1

$$J_{T-1}\left(Q_{T-1}\right) = \max_{P_{T-1} \geq 0} \underset{K_{T-1}}{E} B^{T-1}\left\{M_{t-1}\left(a - bP_{T-1}\right) - \left(f + cP_{T-1}\right)\right\} + J_T\left(a - bP_{T-1} - K_{T-1}\right) \tag{7.2}$$

Períod k

$$J_k\left(Q_k\right) = \max_{P_k \geq 0} \underset{K_k}{E} B^k\left\{M_k\left(a - bP_k\right) - \left(f + cP_k\right)\right\} + J_{k+1}\left(a - bP_k + K_k\right) \tag{7.3}$$

The last three equations refer to the profit functions that govern a period of determined length. We therefore say, for example, that $J_T\left(Q_T\right)$ represents the expected profits in the period of length *T* because it includes benefits generated between *T-1* (the time when the monopolist makes her estimation), and *T* (the final point of the planning horizon). Similarly, the length of the last period is equal to one (and consists of points 0 and 1), since at point 0 the monopolist makes the first estimation of her profits.

4.3.2. Simulation

In order to analyze the implications of equations (7), we carried out several simulations based on information from the projects presented by the winning companies of the bidding contests for distributing natural gas in Mexico. This simulation exercise included several steps.

We first calculated the distinct parameters of the demand and cost functions, as well as the values of M_0, P_t, F_t and Q_t, for the industrial service and for most of the companies (nine of a total of fourteen).[22] We ran several regressions with usage-charge and quantity series to estimate the parameters of the demand function, respecting the relation $Q_t = a - bP_t \ \forall P_t \leq \frac{a}{b}$. The values of fixed and marginal costs, the fixed charge F_t, and the companies' forecasts regarding Q_t were taken from the distribution projects for the industrial service. M_0 was directly computed from restriction $F_t = Q_t\left[M_0 - P_t\right]$, for $Q_t = N$, and kept constant over the five years. P_t was estimated through a more indirect process assuming that the data provided by the investment projects was $P_t(M)$, or the usage charge associated to the final volume of the accumulated demand, and not $P_t\left(Q_t\right)$. We therefore established a linear relation between that usage charge and the other volumes so as to obtain the usage charges of remaining periods. This assumption is justified by the fact that P_t is really a markup (or *surplus price*) that linearly increases or decreases with Q_t, as we will next show.

If we consider that $P_t = a - bQ_t$ is the inverse linear demand function, it becomes clear that a monopolist trying to maximize profits will seek to make her marginal income equal to her marginal cost, or that $MI = a - 2bQ = c$. This means $P_t = c + bQ_t$, or that the usage charge

[22] Some companies did not provide data on volume of demand according to the available information of CRE's web page: http://www.cre.gob.mx

established by the monopolist is a surplus price over the marginal cost that linearly increases or decreases whenever Q_t respectively augments or decreases.[23] If the monopolist selects her optimal price policy based on such a trajectory, we say that she followed a *simple-price strategy*. When she chooses any other trajectory, we say that she followed a *combined-price strategy*.

The second step consisted on determining the values of K and B to analyze the effects of the conduct of the firm (risk averse or risk loving) and the modification of the uncertainty conditions over the optimal P_t and consumer surplus. The probabilities assigned to K_t were calculated on the bases of different associated stochastic processes. The procedure included three types of estimates of the following national demand equation for industrial gas services, initially formulated by Al-Sahalawi and Boyd (1987), and Balestra and Nerlove (1996):

$$LnACIG = B_0 + B_1 LnPIG + B_2 LnIGP + B_3 LnNet + \mu \qquad (8)$$

where:

ACIG=Apparent Consumption of Industrial Gas

PIG=Price of Industrial Gas

IGP=Industrial Gross Product

Net=Pipeline Network

μ=stochastic term

The values of the three estimates were contrasted with the values obtained from a more general regression ran by López-Sandoval (1999) for the Mexican case. Since both types of regression have the same structural form, we considered Lopez-Sandoval´s regression to be the

[23] Consequently, since *c* is assumed to be constant, P_t reflects a monopolist's market power that grows whenever the surplus price is larger, as is expressed by its *Lerner* index $\frac{P_t - c}{P_t} = b\frac{Q_t}{P_t} = \frac{1}{\eta}$, where η is the price elasticity of

real demand, while ours the estimated one. Differences between the two types of values bring about the residuals.

For the first estimate of (8) we performed a MLS linear regression by assuming normality in μ[24]. We call this estimate the normal hypothesis. The second estimate is based on a Poisson regression. In this regression each $\hat{y}_i$ is derived from a Poisson distribution with changing parameters of intensity, λ_i, which are associated with the regressors x_i.[25] In particular we use a Poisson maximum-likelihood regression with the following structural form $\ln L = \sum_{i=1}^{n} \left[-\lambda_i + y_i B'' x_i - \ln y_i \right]$, where ln$L$ is the log of the likelihood function.[26] This is what we call the non-homogeneous Poisson hypothesis or simply the Poisson hypothesis. The third estimate is a random walk in which demand for gas (or apparent consumption) of y_t is set equal to last period's demand plus a white-noise term: $y_i = y_{i-1} + e_i$.[27] This is the random walk hypothesis.

Each hypothesis assumes a particular behavior in firms' demand forecasts. Normal distribution gives a complete account of what a producer expect from a smooth forecast, mainly

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demand.

[24] In this case, equation (8) was represented by the basic equation $\hat{y} = X\hat{B} + e$, where the residuals $e = y - \hat{y}$ were obtained after assuming that the random term was iid N$(0, \sigma^2 I)$. The values of y were extracted from Lopez-Sandoval´s regression, while the values of $\hat{y}$ were calculated from (8). This observation is also valid for the rest of estimates.

[25] A Poisson process with changing parameters λ_i is called a non-homogeneous Poisson process.

[26] The main property of this equation is that $\frac{\partial LnL}{\partial \beta} = \sum_{i=1}^{n} (y_i - \lambda_i) x_i = 0$

[27] In other words we do not include here the independent variables of (8). The random walk is a special case of the AR(1) process $y_i = a_o + a_1 y_i + e_i$, when $a_0 = 0$ and $a_1 = 1$. This process is assumed here to be stationary since

because this distribution is stable in relation to its first and second moments (mean and standard deviation). On the contrary, non-homogeneous Poisson and random walk processes are stochastic processes that fit in well in more volatile scenarios. In particular, they are helpful in describing situations where firms' forecasts are modeled as changeable and independent variations throughout demand (non-homogeneous Poisson) or as dependent variations on demand of previous years (random walk).

Regressions were run over a period of thirty years by using the statistical package STATA. Different outcomes were obtained from the three hypotheses according to data from *Pemex* (1996) and *Secretaría de Energía* (1997), and residuals were calculated for each regression as a percentage of the observed demand. Once these results were obtained, we calculated the values of *K* by multiplying the residuals by each firm's demanded quantity. In this way, three sorts of *K* were obtained, one for each hypothesis, and measured in comparable units.

We then calculated the changes in demand for a representative firm (*Compañía Nacional de Gas*) that undergoes different levels of uncertainty or rather different variations in *K*. Changes in demand for each annual period were estimated by dividing, first, the whole series of 30 years among five periods (each one equivalent to 6 years of regression) and, then, taking the average of residuals in each period. Lastly, the probabilities assigned to each *K* were calculated as the relative frequencies of the residuals.

The third step consisted of feeding equations (7) so as to estimate the Jacobians or optimal value equations for each period and each firm. The results on P_t^* and Q_t^*, were obtained through the *Mathematica* program using two values for B (0.1 and 0.9) and three series of

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we suppose that the root of $1 - ax = 0$ lies outside of the unit circle (or more technically, that $|a| < 1$). The white noise was modeled as an uncorrelated random term with zero mean and constant variance.

values for K both for each period and for each.[28] Each value of P_t^* and Q_t^* was discriminated from a set of three usage charges and three quantities (the feasible set) for each period. This set was composed of a usage charge and a quantity calculated from applying three different values of K.[29]

Finally, in the fourth step we estimated consumer surplus by means of equation (10), using P_t^* and Q_t^* previously obtained for each value of B and K:

$$\Delta S \equiv \sum_{t=1}^{T} B^t \left[S_t - S_0 \right] \tag{10}$$

where:

$$S_0 \equiv \int_{P_0}^{T} Q_t(P_t) dP_t$$

$$S_t \equiv \int_{P_t}^{T} Q_t(P_t) dP_t - F_t$$

Since P_t^* and Q_t^* are respectively measured in *pesos* per *gigacalorie* and *gigacalories*, consumer surplus represents the total income transferred to consumers in *pesos*.

4.3.3. Results

Consumer surplus generally increases when firms are more risk averse.[30] In general terms, consumer surplus also tends to increase as uncertainty becomes higher.[31] More specifically, we found for the case of established firms that larger levels of uncertainty imply

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[28] Of the chosen firms, five are already-existing companies while the others are companies of recent creation.

[29] The three values of *K* result from adding up and subtracting the original values of Q.

[30] When *B* moves from 0.1 to 0.9, average consumer surplus increases from \$16,680.44 to \$18,857.00 in the normal case, from \$14,763.55 to \$66, 435.55 in the random-walk case, and from \$15,525.77 to \$69,866.77 in the Poisson case.

increases in consumer surplus.[32] The reason is that such firms preferred to supply most of their distribution volumes during the first two years through low usage charges, precisely when the non–normal processes implied an increase of uncertainty levels.[33]

On the contrary, larger levels of uncertainty tend to decrease consumer surplus in the new distribution projects.[34] New firms distribute more evenly their distribution volumes during the five years and tend to have higher profits by fixing higher usage charges at the expense of a diminishing consumer surplus. Notwithstanding, the simulation exercise let us conclude that, for both established and new firms, consumer surplus will rise as a whole when uncertainty increases because of the larger resource transfers from the established firms to consumers.

Additionally, all firms chose combined-price strategies. None of the companies followed the simple-price strategy. They seek to combine low usage charges during the first periods with high usage charges in the last periods. This pattern becomes clearer for established firms than for new firms as uncertainty increases, since the latter seek to choose higher usage charges during the initial stages under the Poisson hypothesis than under the normal hypothesis. The firm's low usage price strategy and, hence, the general rise in consumer surplus under increasing values of uncertainty, is due to the cumulative restriction $Q_T \geq N$. The regulator requires that firms meet a determined capacity demand by the fifth year of operation. If the firm's forecast is very erratic

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[31] Uncertainty becomes higher as *K* vary from a normal distribution to a random-walk process all the way to a Poisson distribution process. When *B* equals 0.9, average consumer surplus grows from \$55,137.77 (normal case), to \$66,435.55 (random-walk case), and to \$69,866.77 (Poisson case).

[32] When *B*=0.9, average consumer surplus of established firms grows from \$18,857 (normal case), to \$102,179.6 (random-walk case), and to \$109,849.8 (Poisson case).

[33] This remark is more obvious in case of the Poisson hypothesis. The forecast function for the Poisson process varies in direct relation to the number of events recorded by its intensity rate λ_i. The larger the number of events occurring in a determined period the larger the conditional mean value and variance of this process. This is so, because $E[y_i / x_i] = Var[y / x_i] = \lambda_i = \ell^{B_0 + Bxx_{1i} + B_2 x_{2i} + B_3 x_{3i} + B_4 x_{4i}}$. Therefore, if the established firms tend to concentrate their Q^* in the first two years then one would expect that their forecasts in these years were less accurate than in the rest ones since their variance λ_i is larger.

(let us say, because the real demand behaves as a random walk rather than as a normal distribution), it will search to lower its usage charge in order to promote more capacity use.

5. Concluding Remarks

In this paper we show that average-revenue regulation preserves under demand uncertainty some of its undesirable properties previously studied in the regulatory economics literature. When the current-period output is used to calculate average revenue, consumer surplus tends to decrease as the firm is more risk loving and when there is less demand uncertainty.[35]

In absence of incentives for strategic non-linear pricing, and an intertemporally constant fixed charge, stochastic effects on demand forecast cause firms to set optimal usage charges and demanded volumes in a very particular fashion. While established firms look for protecting themselves from the cumulative constraint by diminishing their usage charges –and thereby increasing consumer surplus--, the new projects generate less consumer surplus by setting higher usage charges. However, for both kinds of firms, lower values of risk aversion and uncertainty imply smaller values of total consumer surplus.

The objective of our simulation exercise was to analyze the effects of the correction factor K on the producer's decisions subject to average-revenue regulation in volatile scenarios. This kind of analysis should contribute to study how much the stochastic effect can nullify or encourage the strategic intertemporal effect. The conclusions that we obtain signal the important countervailing effects arising from introducing the K factor. A future task will be to analyze

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[34] When B=0.1, average consumer surplus of new firms decreases from \$14,152.75 (normal case), to \$4,834.75 (random-walk case), and to \$4,419.48 (Poisson case).

[35] Sappington and Sibley (1992) find that, as the planning horizon is extended, strategic pricing may cause a decrease in consumer surplus unless the value of the discount rate B is very high with respect to a benchmark discount rate. In our case 4.3, the binding assumption for the average revenue constraint cancels the possibility of strategic pricing but the stochastic effect of the correction factor implies a decrease in consumer surplus when the level of B decreases.

whether our results are still valid when the assumption of lack of strategic conduct is lifted and, also importantly, when we change two aspects of the optimization problem in system (4).

The first aspect is related to the cost function. It is clear that a more realistic way of modeling the cost function of a monopolist that introduces technological improvements should be represented by a function of the type $c(Q_t) = f - dQ_t^2$, where $d \lessgtr 0$ indicates increasing or decreasing returns to scale, respectively, and not by a linear cost function.

The second aspect concerns the evaluation of kinked demand curves of the type $P_t = a - b\theta[Q_i]$ ($i = 1,\ldots,n$) with the purpose of analyzing the strategic conduct of monopolists that operate under diverse product differentiation parameters θ, and not only under a single product. In such a case, it is very probable that the cross elasticity of their products should be another factor affecting the rebalancing between the fixed and usage charges. Under uncertainty conditions this would surely cause diverse selection patterns for P_t^*, Q_t^* and F_t^* that have not yet been analyzed.

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