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PRICING LIQUID PETROLEUM GAS IN MEXICO

1. Introduction

The economics of oil and gas in Mexico are difficult and many of the issues involved are very subtle. It is not surprising that there is substantial misunderstanding of many of the issues involved. The difficulties arise from three sources. First, the national oil company Petroleos Mexicanos (PEMEX) is a monopoly and many of the markets involved are regulated. Prices are not a good guide for economic decisions as to production. PEMEX must solve a very difficult programming problem to reach decisions as to quantities produced. Second, oil gas and natural gas liquids are often produced jointly and in such cases it is impossible to allocate costs of production to a specific product.¹ Finally, the goods produced are substitutes in consumption. Gas and oil are substitutes in the generation of power; natural gas liquids, gas and oil are substitutes as feedstocks. This creates very difficult problems in regulating prices. The Comision Reguladora de Energía (Energy Regulatory Commission) has been given the responsibility of regulating the price of liquid petroleum gas (LPG), natural gas and electricity. They are attempting to link the prices in Mexico to world markets.

This paper considers the means by which LPG prices in Mexico can be tied to observable world market prices in an economically defensible fashion. We begin by considering the essentials of the market for LPGs in North America and the Gulf of Mexico, demonstrate that it is appropriate to tie prices in Mexico to the readily observable LPG prices at Mont Belvieu, Texas, and calculate approximate values for LPG prices at the points of import (or export) of LPG into Mexico.² We then consider a detailed linear programming model of LPG import, export and distribution in Mexico (a model proposed by PEMEX and approved by CRE, to serve as the basis for pricing in Mexico) and demonstrate that the dimensionality of

¹See M. A. Adelman, (1963).

²Mont Belvieu is located 20 miles northeast of Houston and has long been the center of the US market for natural gas liquids (NGL). There are four large fractionators that produce 23 million gallons per day of finished product in Mont Belvieu. Mont Belvieu has the largest NGL storage facilities in the world. Located in underground salt domes, the total storage capacity exceeds 4,000 million gallons. The market is large so the price at Mont Belvieu is used for trading in Texas, Louisiana and throughout the Caribbean basin. LPG, butane and propane, are a subset of NGL which include ethane, isobutane, and natural gasoline.

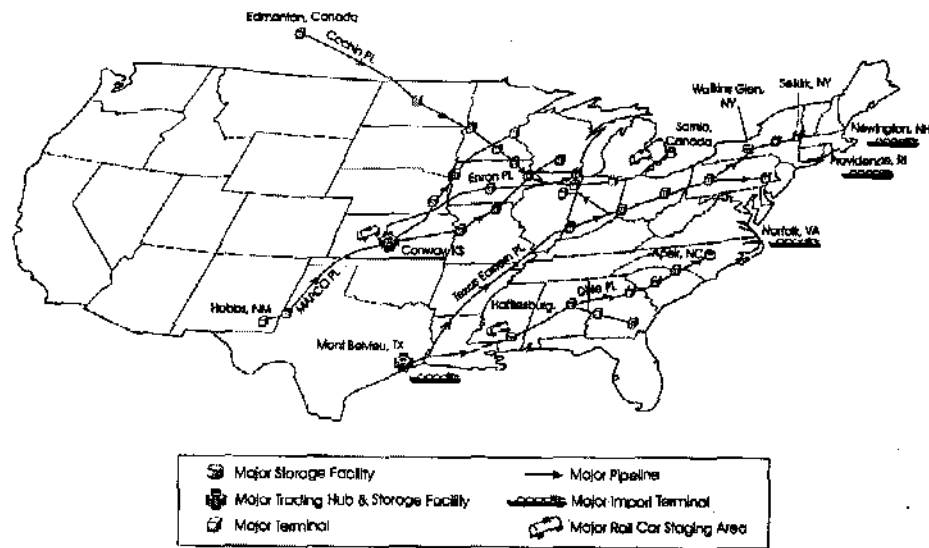
LPG from South America and North Africa is also traded at Mont Belvieu. One of the reasons that LPG trades in an international market is that NGL becomes liquid at temperature of about 0 degrees F. By contrast, natural gas becomes liquid at about -275 degrees F.

Thus, it is relatively cheap to liquefy and transport LPG. It costs about \$5.00 to ship a ton of LPG 1000 miles by sea. This is approximately \$.10 per MMBTU (million BTU) or \$.02 a gallon. The cost of transporting LNG a distance of 1000 miles by sea is approximately \$.30 per MMBTU with a fixed cost of liquefaction and regasification of approximately \$1.40 to \$1.85. See M. D. Tusiani (1997).

the problem can be greatly reduced without loss of information about optimal pricing.³ Finally, we construct an appropriate simplified model which incorporates all information essential to the pricing question, and derive relationships which should hold between prices in Mexico and prices in world markets.

Mexico can import and export LPG by sea at the terminal at Pajaritos on the Mexican Gulf coast. It can also import LPG by truck and pipeline on the United States border and export LPG from its Pacific coast. PEMEX has proposed using a very large programming model to link the Mexican market for LPG with the international market. This is a very large model (several hundred equations) that is not very transparent to use in the formulation of policy. We are going to argue that it is possible to reduce the dimensionality so that it is possible to formulate the problem of pricing LPG in Mexico with a model that is analytically tractable and provides some intuition as to policy. Further, we show that because of the linear nature of the constraint set, the optimal price for the stock of LPG in Mexico is independent of the specification of any reasonable objective function. This is not surprising, but the question has come up in the discussion of policy.

2. Essentials of the North American LPG Market: Implications for Mexico.



Source: Energy Information Administration.

Figure 1

³See CRE's resolution RES/O85/97. In this legal document the CRE approves the methodology proposed by PEMEX to price domestic LPG.

The US is a net importer of LPGs, with net imports running about 100 thousand barrels per day. The majority of this material comes from Canada via pipeline, but significant volumes are imported as waterborne cargoes from Algeria and Venezuela. Depending on market conditions in various parts of the world, the US also imports LPG from Europe (North Sea) and the Middle East (Saudi Arabia, UAE). In the future, as new gas processing facilities come on stream, Nigerian LPG can be expected to flow into the US. Of particular interest to Mexico, is the fact that an annual average of 35 million barrels a day (MBD) of LPGs are imported into US PADD 3 (the Gulf Coast region) from outside North America. About 70 percent of this material comes from Algeria, the remainder from Venezuela. These imports are landed at Houston, where they can move into storage facilities at Mont Belvieu.

It should be noted that there is considerable seasonal variation in these imports. In winter, LPG prices in Europe typically rise sufficiently to attract all of the waterborne LPG available from Africa and South America. Under these conditions, it becomes uneconomic to ship this material to the USGC, and imports cease. In summer, however, European prices drop, imports into the US become attractive, and some 50-60 MBD moves into the USGC.

When the US is importing LPG into the USGC, prices at Mont Belvieu should equate to the landed cost of imports (including terminal costs)⁴. Noting further that the sailing distance from Algeria to Pajaritos (c. 5500 n.m.) differs only slightly from that from Algeria to Houston (c. 5400 n.m.), the landed cost of imports into Pajaritos should be approximately the same as the landed cost in Houston, differing only by the amount of the differences in terminal costs. Consequently, one would expect the price of LPG at Pajaritos to be the same as the price at Mont Belvieu.

When prices of African and South American LPG are too high to permit imports into the US, Mont Belvieu may well become the most economic source of product for import into Pajaritos. Under these conditions, one would expect the landed cost of imports at Pajaritos (and the price) to be approximately Mont Belvieu plus 2.5 to 3 cents per gallon.⁵

⁴Butane imported to the U.S. is used as a feedstock in petro-chemicals and must be fractionated into normal and iso-butane before entering the market. This should be treated as an addition to terminal costs for butane imported into the U.S. LPG in Mexico is used as a source of heat and fractionation is not necessary at Pajaritos

⁵This number was suggested as a reasonable approximation by Purvin and Gertz. It should be noted that the exact cost of moving LPG will depend on the demand and supply conditions in the charter market for LPG carriers.

Mexico imports LPG by pipeline and truck along its northern border. These imports are of product which would otherwise flow by pipeline into the market in the interior of the United States. Thus, to assess prices at the border, and their magnitude relative to prices at Mont Belvieu it is necessary to consider the pattern of distribution of LPGs in the US market. As can be quickly ascertained from the attached map (Figure 1), there are two major storage points for LPGs in the United States, Mont Belvieu and Conway, Kansas. LPG moves by pipeline from Mont Belvieu into the midwest and eastern portions of the US. Product moves from Conway into the midwest, where it must compete with material coming up Mont Belvieu and imports coming in by pipeline from Canada. Given the locations of Conway and Mont Belvieu relative to their competition point in the Chicago region, one would expect LPG prices at Conway to be approximately the same as they are in Mont Belvieu. This indeed turns out to be the case most of the time, as can be seen in the following graph prepared by the US Energy Information Administration. (see Figure 2 or Table 1)

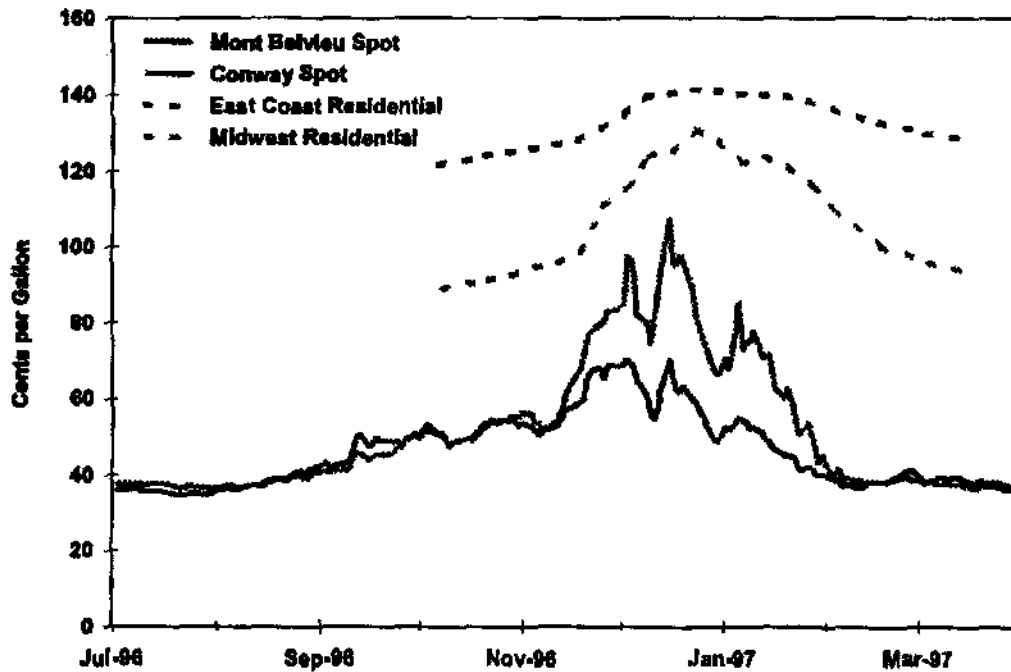


Figure 2

In the winter of 1996-97, low propane stocks, high crop-drying demand in the fall, and cold weather combined to create a shortage of propane in markets served by Conway, which could not be reached by product from Mont Belvieu due to pipeline limitations. Consequently, Conway prices reached levels significantly higher than those in Mont Belvieu. However, this is a highly unusual situation, and

under normal circumstances, one finds the price of propane at Conway to be essentially the same as Mont Belvieu, i.e Mont Belvieu even.

Natural gas liquids are extracted at gas processing plants in New Mexico and West Texas. However, there is insufficient capacity in the region to fractionate all these liquids into marketable products including propane and butane. Thus, to meet product demand in the area LPGs must flow back to the region from fractionation plants elsewhere, e.g. Conway. Consequently, one should expect the price of LPG at the Mexican border to be equal to Conway (or equivalently, Mont Belvieu) plus transportation costs of approximately 3 cent per gallon.

Table 1:
Prices of Propane (US cents per Gallon)

	Northwest Europe	Mont Belvieu	Conway	Conway vs. MB
1996				
Jan	41.43	35.44	36.45	1.01
Feb	47.35	38.98	39.02	0.04
Mar	39.66	36.88	38.19	1.31
Apr	33.52	35.57	34.60	-0.97
May	31.65	34.84	34.58	-0.26
Jun	29.81	34.84	37.37	2.53
Jul	29.91	35.56	37.30	1.74
Aug	33.16	38.36	38.04	-0.32
Sep	45.11	47.04	44.75	-2.29
Oct	50.53	51.32	51.66	0.34
Nov	54.79	58.32	64.87	6.55
Dec	68.70	60.82	85.98	25.16
1997				
Jan	78.64	47.35	63.32	15.97
Feb	43.75	38.65	39.07	0.42
Mar	37.04	38.49	37.17	-1.32
Apr	35.34	34.87	35.25	0.38
May	37.12	35.27	36.53	1.26
Jun	35.63	34.40	35.86	1.46
Jul	35.28	34.84	34.54	-0.30
Aug	35.82	36.93	36.32	-0.61
Sep	37.21	38.67	37.95	-0.72
Oct	39.25	39.83	37.34	-2.49
Nov	44.57	36.03	35.08	-0.95

Source: Energy Information Agency

3. The PEMEX Model

PEMEX has proposed a linear programming model to price LPG in Mexico. The model is characterized by the following:

N - demands given by the quantity vector $\mathbf{D} = (D_i), i = 1, N$

M - domestic supply points given by the quantity vector $\mathbf{Q} = (Q_j), j = 1, M$

E - export demands characterized by the price vector $\mathbf{q} = (q_k), k = 1, R$

K - import supply points characterized by the price vector $\mathbf{p} = (p_j), j = M+1, S$

T - transport modes, $t = 1, T$

X = is the volume transport to demand i from source j using transportation mode t at cost.

$y = y_j$ is the volume of imports from source j

$z = z_k$ is the volume of exports to demand k .

The objective function PEMEX is to minimize the cost of transporting LPG plus the cost of net imports:

$$\sum_{i=1}^N \sum_{j=1}^S \sum_{t=1}^T c_{ijt} x_{ijt} + \sum_{j=M+1}^S p_j y_j - \sum_{k=1}^R q_k z_k \quad (1)$$

The first constraint requires that all demands be satisfied:

$$\sum_{j=1}^S \sum_{t=1}^T x_{ijt} = D_i, i = 1, N \quad (2)$$

The second constraint requires that domestic production be consumed or exported:

$$\sum_{i=1}^N \sum_{t=1}^T x_{ijt} + z_j = Q_j, j = 1, M. \quad (3)$$

The third constraint requires that imports be consumed or exported:

$$\sum_{i=1}^N \sum_{t=1}^T x_{ijt} + z_j = y_j, j = M+1, S \quad (4)$$

This model is very general and very detailed.⁶ If the vectors as to the quantities demanded and supplied are correct, the model will give a detail allocation of LPG. The duals of the model are the values of the product and the cost of meeting the demands. However, the model is too detailed to be very transparent as to the relationship between the variables. The PEMEX model has more than 1500 variables and 500 equations. Further, for the purpose of determining the price of LPG in Mexico, the key variable we actually are interested in the dual associated with the stock of LPG. Large linear models are very easy to compute, but the solution can be discontinuous and the results can be less than transparent. Fortunately, for the purpose of determining the price of LPG, the Maximum Theorem permits us to reduce the PEMEX model to a model whose dimensionality is that of the input and constraint set. This model in can be solved analytically.

4. Dimensionality of the problem

In this section we will show that the PEMEX model can be reduced in dimensionality without loss of information as to the value of the duals. Define:

$$F(\mathbf{X}) = \sum_{i=1}^N \sum_{j=1}^S \sum_{t=1}^T c_{ijt} x_{ijt} \quad (5)$$

$$\mathbf{p}'\mathbf{y} = \sum_{j=M+1}^S p_j y_j \quad (6)$$

$$\mathbf{q}'\mathbf{z} = \sum_{k=1}^R q_k z_k \quad (7)$$

where the notation is a given in Section 3. The PEMEX objective function can the be written as:

$$F(\mathbf{X}) + \mathbf{p}'\mathbf{y} - \mathbf{q}'\mathbf{z} \quad (8)$$

⁶The PEMEX model includes transport modes for both imports and exports and the objective function considers that imports may come from several suppliers while exports may be directed from one export point to several markets. It is not difficult to show that equations (1) to (4) are equivalent.

Finally, let:

$$\Gamma(\mathbf{X}, \mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q}) \geq 0 \quad (9)$$

be the linear constraint set given by (2), (3) and (4). Let $\Omega(\mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q})$ be the set of feasible allocations. We can first define the following problem of minimizing transport costs for a fixed value of imports and exports. This is given by the problem:

$$G(\mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q}) = \min_{\mathbf{X}} F(\mathbf{X}) \quad (10)$$

subject to (9) for fixed values of \mathbf{y} and \mathbf{z} in $\Omega(\mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q})$. The Lagrangian for this problem is:

$$L = F(\mathbf{X}) + \lambda \Gamma(\mathbf{X}, \mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q}) \quad (11)$$

From the Envelope Theorem⁷, we know:

$$\frac{\partial G}{\partial \mathbf{y}} = \lambda \frac{\partial \Gamma}{\partial \mathbf{y}} \quad (12)$$

$$\frac{\partial G}{\partial \mathbf{z}} = \lambda \frac{\partial \Gamma}{\partial \mathbf{z}} \quad (13)$$

Now consider the problem of minimizing the net cost of imported LPG given a vector of production and demands:

$$H(\mathbf{D}, \mathbf{Q}) = \min_{\mathbf{y}, \mathbf{z}} [G(\mathbf{y}, \mathbf{z}, \mathbf{D}, \mathbf{Q}) + \mathbf{p}'\mathbf{y} - \mathbf{q}'\mathbf{z}] \quad (14)$$

⁷See A. Mas-Colell, M. D. Winston and J. Green, *Microeconomic Theory*, p.964.

The first order conditions for (14) are given by:

$$\mathbf{p} + \frac{\partial G}{\partial \mathbf{y}} \geq 0, \quad \mathbf{y} \left[\mathbf{p} + \frac{\partial G}{\partial \mathbf{y}} \right] = 0 \quad (15)$$

$$-\mathbf{q} + \frac{\partial G}{\partial \mathbf{z}} \geq 0, \quad \mathbf{z} \left[-\mathbf{q} + \frac{\partial G}{\partial \mathbf{z}} \right] = 0 \quad (16)$$

If we substitute in the (15) and (16) from (12) and (13), we get:

$$\mathbf{p} + \lambda \frac{\partial \Gamma}{\partial \mathbf{y}} \geq 0, \quad \mathbf{y} \left[\mathbf{p} + \lambda \frac{\partial \Gamma}{\partial \mathbf{y}} \right] = 0 \quad (17)$$

$$-\mathbf{q} + \lambda \frac{\partial \Gamma}{\partial \mathbf{z}} \geq 0, \quad \mathbf{z} \left[-\mathbf{q} + \lambda \frac{\partial \Gamma}{\partial \mathbf{z}} \right] = 0 \quad (18)$$

The problem defined by (14) has a dimensionality less than or equal to the number of import and export activities. The vector of shadow prices is determined by the linear system given by (17) and (18). It is independent of the particular structure of the function. The convexity of the feasible set and the assumption that the objective function is linear insures that the two problems have the same solution. An objective function that maximize welfare as a function of the demands for LPG will give the same results as the cost minimizing model proposed by PEMEX because the price of LPG is ultimately determined by the constraints.

5. The Pricing Model

The structure of imports and exports and supply in Mexico is depicted in Figure 3 below.



Figure 3

LPG is imported and exported at Pajaritos by sea. LPG is exported by sea to South America from the Pacific coast. It is imported on the U.S.-Mexico border by pipeline and truck. LPG is consumed in the center of Mexico and this demand is primarily supplied by pipeline. The balance of this demand is mostly in the north of Mexico. The numbers in Figure 3 are the price per gallon proposed by PEMEX based on the price quoted at Mont Belvieu (MB).

We use this structure to construct a model characterized by two modes of import, two modes of export, one point of production and two sources of demand. The structure of the model is depicted in Figure 4 below. This model is slightly more complicated than necessary as it is designed to clarify some of the points that have been raised by the PEMEX model and are being discussed. The notation of this model is the same as the PEMEX model except that we have been able to reduce the

dimensionality of the transport variables by eliminating dominated activities. This is done by noticing that the assumption that transportation costs are linear implies that between any two points it is only optimal to use one mode of transport (we are assuming there is no congestion) if that is feasible. If more than one mode is necessary to transport the gas at least cost (i.e. pipeline part of the way and then truck), then it is possible to aggregate these cost to a cost per unit transported.

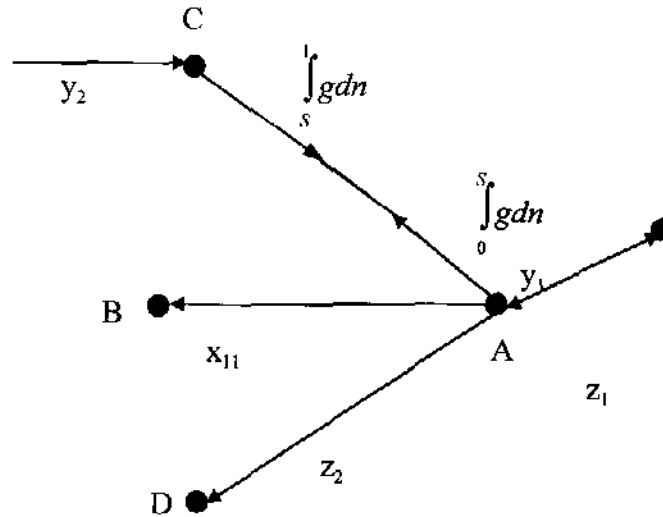


Figure 4

The essential features of the distribution system for LPG are represented by the network given in Figure 4 above.

In this network, LPG is produced and imported at point A. This gas can be transported to point B or to points on a line between A and C. Gas can be imported at points A and C. Thus we can think of A as Pajaritos, B as a point of demand in the center or south of Mexico and the line A-C as demand in the north of Mexico. D can be thought of an export market such as Central or South America.

We will make an assumption similar to Hotellings and assume that the distribution of demand on the line A-C is given by the distribution function $g(s)$. Total demand on the line A-C is then given by:

$$D_2 = \int_0^s g(n)dn + \int_s^1 g(n)dn \tag{19}$$

It is assumed that the cost of moving LPG from point A to a point located at n is $c_2 n$ and the cost of moving LPG from point C to a point located at n is $c_2(1-n)$. The point s is what is referred to as the “arbitration point,” the point where the price

of LPG from point A or point C is equal. The distribution function $g(s)$ defines demand on the line A-C. It is general and could have mass points.

The objective function of our model is:

$$\min c_{11}D_1 + \int_0^{s_1} g(n)c_2ndn + \int_s^1 g(n)[c_2(1-n) + p_2]dn + p_1y_1 - q_1z_1 + q_2z_2 \quad (20)$$

the constraints are:

$$z_1 + z_2 + x_{11} + \int_0^{s_1} g(n)dn - Q_1 - y_1 = 0 \quad (21)$$

$$D_1 - x_{11} = 0 \quad (22)$$

$$\int_s^1 g(n)dn - y_2 = 0 \quad (23)$$

$$z_2 \leq R \quad (24)$$

where R is a constraint on exports to Central or South American markets.

6. Imports and Exports

The relationship between imports, exports and the price of LPG can be examined in two very simple models. In the first model the consumption of LPG has been reduced to one activity and there is one export and one import activity. (See Figure 5)

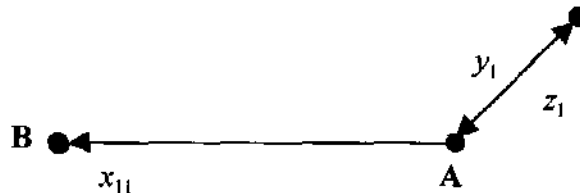


Figure 5

The objective function can be written as:

$$\min \pi = c_{11}x_{11} + p_1y_1 - q_1z_1 \tag{25}$$

where constraints are now:

$$z_1 + x_{11} - Q_1 - y_1 = 0 \tag{26}$$

$$D_1 - x_{11} = 0 \tag{27}$$

We can use equation (27) to eliminate x_{11} and plot equations (25) and (26) for the two possible cases.

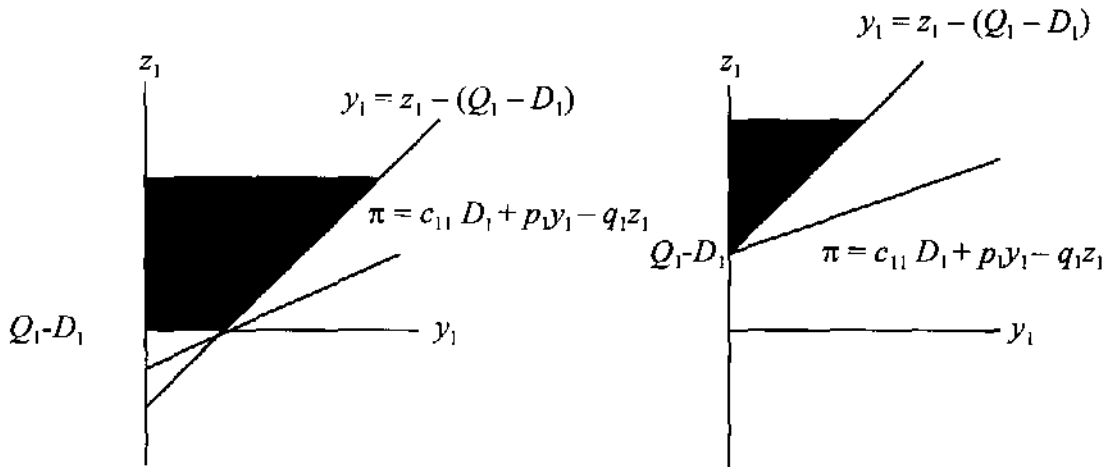


Figure 6

Figure 6 illustrates the two possible cases. If $Q_1 - D_1 < 0$, then the solution is $y_1 = D_1 - Q_1$ and $z_1 = 0$. If $Q_1 - D_1 > 0$, then the solution is $z_1 = Q_1 - D_1$ and $y_1 = 0$. The shadow price of LPG is thus either p_1 or q_1 .

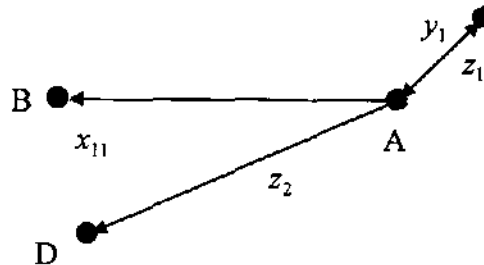


Figure 7

The problem is slightly more complicated if we allow two export activities. Figure 7 depicted a model in which there is one activity for the consumption of LPG and two export activities. The objective function can be written as:

$$\min \quad c_{11}x_{11} + p_1y_1 - q_1z_1 - q_2z_2 \quad (28)$$

where constraints are now:

$$z_1 + z_2 + x_{11} - Q_1 - y_1 = 0 \quad (29)$$

$$D_1 - x_{11} = 0 \quad (30)$$

$$z_2 - R \leq 0 \quad (31)$$

If we use (30) to eliminate x_{11} , the Lagrangian can be written as:

$$L = c_{11}D_1 + p_1y_1 - q_1z_1 - q_2z_2 + \lambda[z_1 + z_2 + x_{11} - Q_1 - y_1] + \beta[z_2 - R] \quad (32)$$

where λ is the value of LPG, and β is the dual associated with the export constraint at **B**. The first order conditions are:

$$p_1 - \lambda \geq 0, \quad y_1[p_1 - \lambda] = 0 \quad (33)$$

$$-q_1 + \lambda \geq 0, \quad z_1[-q_1 + \lambda] = 0 \quad (34)$$

$$-q_2 + \lambda + \beta \geq 0, \quad z_2[-q_2 + \lambda + \beta] = 0 \quad (35)$$

If we examine inequalities (33), (34) and (35) we see that the shadow price of LPG, λ , will equal p_1 if imports are positive. If exports are positive, then there are two possible cases (see Figure 8),

- a) if $Q_1 > D_1 + R$ then $\lambda = q_1$,
- b) if $Q_1 < D_1 + R$ then $\lambda = q_2$.

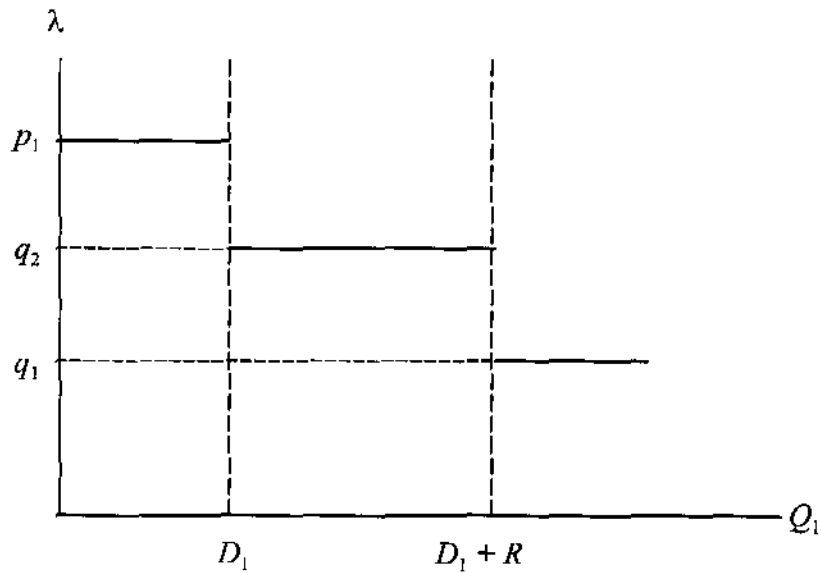


Figure 8

The price of LPG is discontinuous at D_1 and at $D_1 + R$. Note that in the case where $\lambda = q_2$, the linear model may be misleading. It is reasonable to tie the price of LPG to a large market like Mont Belvieu, but it is hard to argue that there is any economic rationality to have the price of LPG in Mexico be established by the price of LPG in South America.

7. Price Gradient and The Arbitration Point

One of the issues that comes up is the role of the price gradient and the arbitration point in determining the price of LPG. Recall that the “arbitration point,” is the point where the price of imported and domestically produced LPG is equal. To study this issue we can maximize the objective function given by (20) subject to the constraint set defined by (21), (22) and (23). For the moment, we will ignore exports to South America. The Lagrangian for this model is:

$$L = c_{11}D_1 + \int_0^s gc_2ndn + \int_s^1 g[c_2(1-n) + p_2]dn - q_1z_1 - q_2z_2 + p_1y_1 + \lambda \left[z_1 + z_2 + x_{11} + \int_0^s g(n)dn - Q_1 - y_1 \right] \quad (36)$$

The first order conditions are:

$$p_1 - \lambda \geq 0, \quad y_1[p_1 - \lambda] = 0 \quad (37)$$

$$-q_1 + \lambda \geq 0, \quad z_1[-q_1 + \lambda] = 0 \quad (38)$$

$$gc_2s - g[c_2(1-s) + p_2] + g\lambda = 0 \quad (39)$$

$$z_1 + z_2 + x_{11} + \int_0^s g(n)dn - Q_1 - y_1 = 0 \quad (40)$$

Let λ^* be the value of λ which solves the maximization. This value depends on whether (37) or (38) is a binding constraint. It is possible that neither constraint binds. Then equation (40) can be solved for s . Equation (39) can be written as:

$$c_2s + \lambda^* = c_2(1-s) + p_2 \quad (41)$$

or

$$\lambda^* = c_2(1-2s) + p_2 \quad (42)$$

We can graph the solution of this equation for the possible values of λ^* .

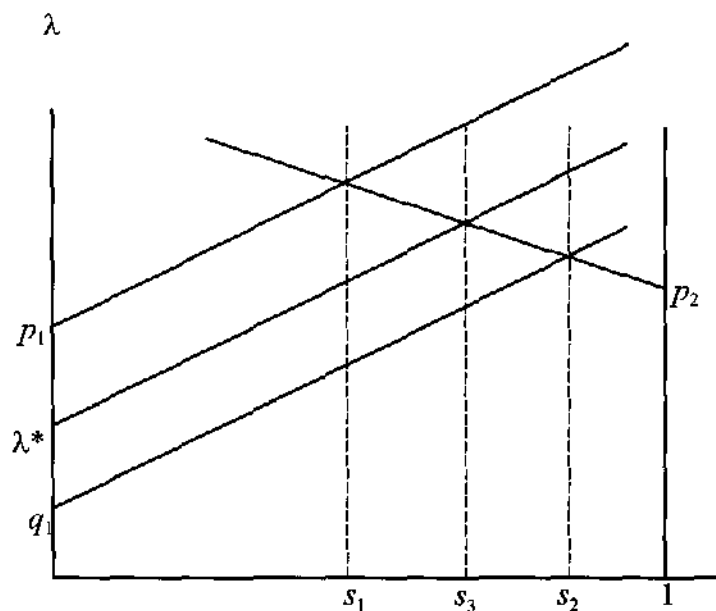


Figure 9

The right hand and left hand side of equation (42) are plot separately as a function of s . The intersection of these lines gives the arbitration point:

- s_1 if LPG is imported and $\lambda = p_1$ or
- s_2 if LPG is exported and $\lambda = q_1$.
- s_3 if LPG is not imported or exported and $\lambda = \lambda^*$.

The arbitration point is the result of fixing the price of LPG at Pajaritos and the United States border or by fixing the price at the United States border and the amount of LPG supplied by PEMEX to the domestic market.

8. Problems with the structure of incentives

CRE has the authority to regulate the price of LPG that is offered for sale in Mexico. It does not have the authority to regulate exports or the use of LPG as petrochemical feed stock. Assume that PEMEX can divert D_u of the amount produced from the domestic market at its discretion. If there are no imports or exports at Point A, then the arbitration point, s_3 is determined by supply of LPG to the domestic market and is given by:

$$\int_0^s g(n)dn = Q_1 - D_1 - D_u \quad (43)$$

where D_u is the amount of LPG supplied to the petrochemical industry and/or exported.

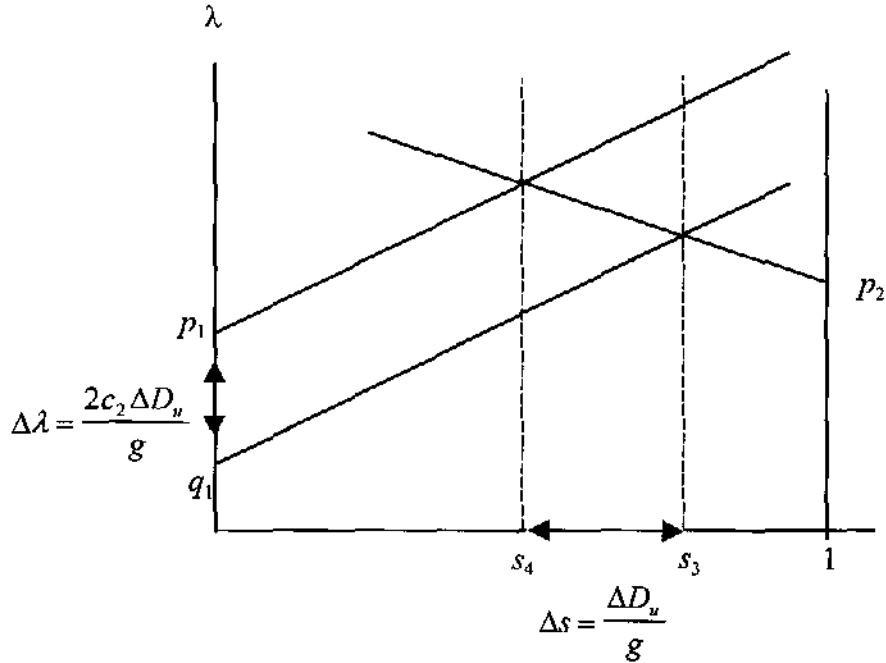


Figure 10

We can use equations (42) and (43) to show:

$$\frac{\partial \lambda^*}{\partial D_u} = \frac{2c_2}{g(s)} \quad (44)$$

The relationship between the price of LPG and D_u is illustrated in Figure 10.

If we approximate $g(s)$ as in the interval Δs constant, \bar{g} , then:

$$\Delta \lambda = \frac{2c_2 \Delta D_u}{\bar{g}} = 2c_2 \Delta s \quad (45)$$

Changing arbitration point by an amount Δs changes the shadow price of LPG by twice the marginal increase in the cost of transportation.

This price increase is then imputed on the entire stock of LPG produce for domestic consumption. There are incentives for PEMEX to divert LPG from the domestic market. This is not a major problem if the price of LPG has a cap of the price of ship's rail at Pajaritos. However, without this explicit cap there are incentives to increase the price of the domestic stock of LPG by exporting production or diverting production to petrochemicals. Let $q(D_u)$ be the net price PEMEX receives for sales to non regulated markets and λ be the net price it receives in the regulated markets as determined by (42). Then the lagrangian associated with maximizing revenues subject to a production constraint is:

$$\pi = q(D_u)D_u + \lambda D_1 + \gamma [Q_1 - D_1 - D_u] \quad (46)$$

The first order conditions can be manipulated to yield:

$$\left[\frac{\partial q}{\partial D_u} D_u + q \right] + \frac{\partial \lambda}{\partial D_u} D_1 = \gamma \quad (47)$$

Since the term $\frac{\partial \lambda}{\partial D_u} D_1 > 0$, it follows that $\left[\frac{\partial q}{\partial D_u} D_u + q \right] < \gamma$. Since the term $\left[\frac{\partial q}{\partial D_u} D_u + q \right]$ is marginal revenue from nonregulated sales, there is an incentive for PEMEX to sell nonregulated LPG beyond the point where marginal revenue is equal to the shadow price of LPG, γ . As, noted above, this problem is not important if a cap on price for LPG at ship's rail at Mount Belvieu is set.

9. Conclusions

This paper studies the implications of linking the Mexican market for LPG to international markets.

We show:

1. If LPG is imported at Pajaritos, the price of LPG should be the import price.
2. If LPG is exported from Pajaritos, the price of LPG should be the export price.

In these two cases, the arbitration point for LPG imported from the US-Mexico border and LPG at Pajaritos is established by price at the border and the price at Pajaritos

3. If LPG is not imported or exported at Pajaritos, then the arbitration point is determined by the balance of LPG that remains after exports. The price of LPG that follow from the programing model is determined by price of gas at the US-Mexico border together with arbitration point.

In the third case, LPG is only imported at the American border. The arbitration point is established by price of gas at the border and the net quantity of LPG supplied to nonregulated markets. If there is not an explicit cap on the price of LPG, then there is an incentive to reduce the supply of LPG by diverting it to nonregulated markets.

In implementing a policy based on this analysis, the key question becomes the actual cost of imports of LPG. On the northern border, that cost is reasonably represented by the Conway (or equivalently, Mont Belvieu) price plus pipeline cost from Conway to the import point, which appears to be on the order of 3 cents per gallon. As for waterborne imports and exports, PEMEX assumes that the price of imported LPG at Pajaritos is the Mont Belvieu price plus 7 cents, that the price realized on exports of LPG from Pajaritos is Mont Belvieu minus 5 cents. These assumptions are based on physical movements of LPG from (or to) Mont Belvieu. However, if international market conditions are such that LPG is being imported on the US Gulf Coast, it is possible to land LPG at Pajaritos at the same cost as imports into the US, implying that the Pajaritos price should be the same as that at Mont Belvieu (adjusted for any differences in the terminal costs at the two locations).

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