

Pricing Natural Gas in Mexico

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Abstract

We study mechanisms for linking the Mexican market for natural gas with the North American market and show that the netback rule is the efficient way to price natural gas. We study the effects of investment in production facilities, reductions in import tariffs and technical export restrictions on domestic natural gas price. Reducing the import tariffs will not increase the importation of natural gas and will have little impact on the price. Further, we show that it is optimal to develop new gas sources closest to the arbitrage point rather than to the center of consumption. We also study the implications of the regulatory framework on Pemex's marketing activities in the forward market for gas.

Key words; natural gas, welfare, pricing, Mexico, regulation

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1. Introduction

NAFTA has resulted in the opening of many of the Mexican markets; many of the institutional and tariff barriers to the free movement of capital and goods have been removed. This paper discusses the linkage of the Mexican market for natural gas to the U. S. and Canadian market. Difficulties arise from three sources. First, the national oil company *Petróleos 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. 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. 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 *Comisión Reguladora de Energía* (CRE) has been given the responsibility of regulating the price of natural gas.

In North America, gas is transported by pipeline. The cost of transporting 1000 cubic feet of gas 1000 miles by onshore pipeline is approximately \$.40 to \$.85. By contrast, the cost of transporting a barrel of residual fuel oil is approximately \$.10 per thousand miles. Since a barrel of residual fuel oil has the energy equivalent of 6000 cubic feet of gas, gas is more than twenty times more expensive to transport than fuel oil. The economics of transportation is a key element in the North American market for gas. This market is based on pipelines and there are pipelines connecting the United States and Mexico.

We begin by considering the essentials of the Mexican pipeline system, and show how the price of natural gas in Mexico is tied to the gas prices in South Texas. We then construct a model of natural gas import, export and distribution in Mexico, and derive the optimal pricing rule of natural gas in the Mexican pipeline system. This pricing rule is the formula that the CRE has implemented and is consistent with the objectives of a regulator seeking to optimize social welfare. Finally, we analyze the impact on the price of Mexican natural gas of reductions in import tariffs, technical export restrictions, new points of production, and forward markets and restrictions on pipeline capacity.

2. The Mexican Natural Gas Market

The Mexican pipeline system is shown in Figure 1. This network is 10, 249 kilometer long. It reaches most of the industrial centers with the exception of the North Pacific part of the country. In 1994 the pipeline system transported 2.4 billion cubic feet of natural gas. This volume includes 130 million cubic feet (mcf) of gas imports, 140 mcf of non associated gas, and 2.1 billion cubic feet (bcf) of associated gas from processing plants. Mexico has approximately 63 trillion cubic feet of gas reserves. In recent years over 38 trillion cubic feet of non associated gas have been discovered near Burgos.¹ These gas fields are close to the Texas border. At present rate of consumption, this is over 35 years of reserves so there is a potential for this gas to be exported to the U. S. market. The pipeline linkage from these discoveries to the U.S. market is currently under expansion.²

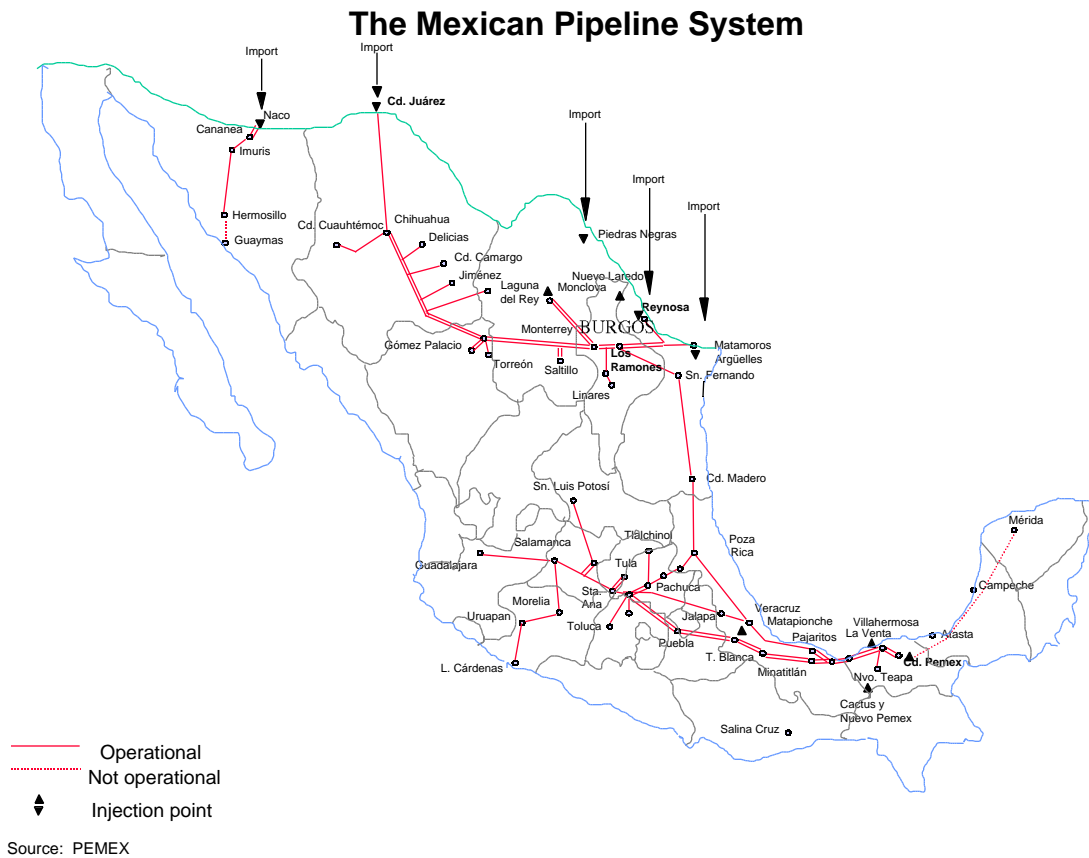


Figure 1

¹Pemex, 1998, *Indicadores Petroleros y Anuario Estadístico*.

²The current export capacity at Reynosa is 175 mcf per day and the import capacity is 300 mcf per day. These capacities are being expanded to 330 and 220 respectively with the Tennessee and Tejas pipelines.

The Mexican pipeline system can be viewed as a "Y" shaped network. Ciudad Pemex is located at bottom of this "Y". This city is located in the Southeast region where Pemex produces associated gas (80% of total natural gas production). In the Northeast arm of the "Y" is Reynosa-Burgos which produces non associated gas (12.3% of total production) and is a link with the Texas pipeline system. At the Northwest arm is Ciudad Juárez which is a point where gas is imported. The physical junction of the three branches of the "Y" is located at Los Ramones.

The CRE regulates the price of gas at Ciudad Pemex price through a netback formula based on a benchmark price in Southeast Texas, the arbitrage point between imported gas and gas produced in Mexico, and the net transport costs. The point where import and domestic flows meet is defined as the arbitrage point. Since the price of imported and domestic gas must be the same at this point, the price of the Mexican natural gas at this point is the sum of the Texas benchmark price plus the transport cost from the border. The price of gas at Ciudad Pemex is the price of gas at the arbitrage point less the transport cost from this point to Ciudad Pemex. The price of gas in Mexico is the price at the Houston Ship Channel adjusted for costs. The price cap for the Mexican natural gas is equal to the price in Southeast Texas, plus transport costs from Texas to the arbitrage point, less transport costs from the arbitrage point to Ciudad Pemex. The arbitrage point is currently located at Los Ramones.

In a static model this price rule would be optimum. However, pricing natural gas is a problem in the theory of the second best. Two equilibrium conditions have to be satisfied for efficiency: spatial and intertemporal conditions. In the spatial market, the price of natural gas must be linked to transport costs while in the intertemporal market the price of natural gas at any two points in time should be linked by the interest rate and the cost of holding natural gas.

The pricing rule based on the Houston Ship Channel price implies an equilibrium in a spatial sense since the marginal cost of imported gas and the marginal cost of domestic gas are the same at the arbitrage point. However, in times of peak demand, the binding

constraints in the supply of gas to market maybe bottlenecks in the pipelines from gas storage reservoirs and non-associated gas fields.the rule may cause intertemporal distortions due to the high cost of transporting and storing natural gas. Thus, linking the US and Mexican natural gas prices introduces into the Mexican market the distortions generated by the US weather. A very cold winter in the Northeast of the USA during 1996-97 caused a dramatic increase in the natural gas bills paid by Mexican consumers.³

When the intertemporal equilibrium condition is violated, is it sensible to impose the spatial condition? The theory of the second best suggests that the answer to this question is not clear. Having the price of natural gas reflect the cost of imported gas means that the marginal gas will be used efficiently in the short run, but imputing this price to domestic production results in rents to Pemex and may create intertemporal distortions. Natural gas should be priced in terms of its scarcity and not in terms of pipeline bottlenecks. One possible distortion is the selection of technology over time.

One of the most important uses of natural gas is in the generation of electricity. In that use, it is a close substitute for fuel oil. The premiums for natural gas over oiled fired alternatives were computed by Stauffer in his study of the economics of transporting liquefied natural gas. He found that gas had a small advantage over fuel oil and that a substantial fraction of that premium could be attributed to environmental concerns.⁴

Another factor in reducing the distortions caused by seasonal variations in the price of gas is the emergence of a broad market in future contracts. This market enables gas consumers in Mexico to hedge against some of the risk created by the weather in the United States.⁵

³ Natural gas price in Mexico increased by 135% between October 1996 and January 1997.

⁴T. R. Stauffer, (1996) "The Diseconomics of long-haul LNG Trading," Occasional Paper No. 26 International Research Center for Energy and Economic Development, p. 4.

⁵The CRE has recently implemented such a mechanism for distributors of natural gas. (See Comisión Reguladora de Energía 1998).

3. Pricing Natural Gas

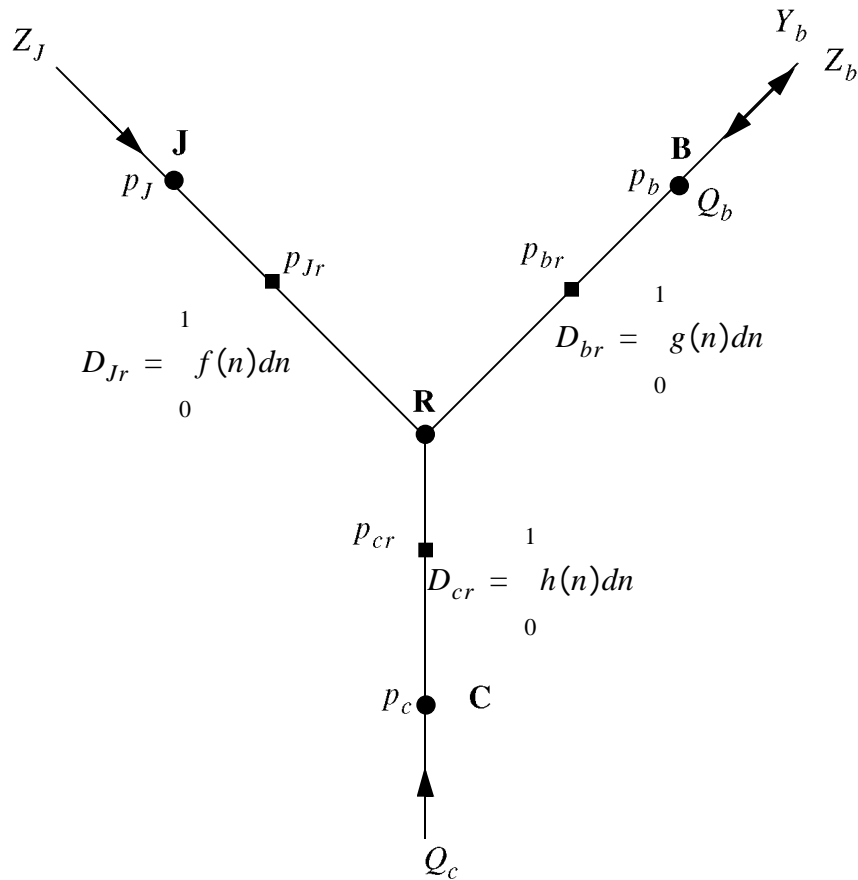


Figure 2

A model of the linkage of the natural gas pipelines to the world markets need only consider the linkages to the Texas pipeline network. Figure 2 captures the essential features of the complete Mexican gas pipeline system. Z_J represents imports at Juárez from West Texas, Q_b represents production at Burgos, and **R** is Los Ramones, the point where the main system and the northwest subsystem are physically interconnected. Demand is distributed on the lines **JR** which represents demand between Juárez and Los Ramones (Monterrey is located on this line), **BR** between Los Ramones and Burgos, and on the line **RC** which represents demand in the center and south of Mexico. **C** is Ciudad Pemex. Assume that the distribution of gas on lines **JR**, **BR**, **CR** is given by the general density functions $f(n)$,

$g(n)$, and $h(n)$.⁶ Gas is supplied at **J**, **B**, and **C** by the amounts Q_a , Q_b , and Q_c . The price at point **J** is given by p_j , at point **B** is given by p_b , at point **C**, by p_c and at point **R**, by p_r . The arbitration point between **J** and **R** is given by r , between **B** and **R**, by s and between **C** and **R**, by t . The points $r = 1$ and $s = 1$ are located at **R**. The point $t = 1$ is located at **C**. Higher values of r , s and t imply that the arbitration point has moved south.

Even in this form, the general solution of this problem is complicated. However, the problem can be simplified by exploiting some technical and institutional properties of the Mexican pipeline network. First, there cannot be equilibrium with three arbitration points. This would require that point **R** be a production source. Second, the capacity of the pipeline at Juárez and the demand on that segment of the pipeline (e.g. Monterrey) are such that gas from West Texas will not reach Los Ramones. This implies that one of the arbitrage points must be in the Juárez-Los Ramones segment of the pipeline. Since gas is produced at Burgos and Ciudad Pemex, there must be an arbitration point delineating these two sources of production. Thus, there are two arbitration points and one of them must be in the Juárez-Los Ramones segment of the pipeline. To avoid the use of Kuhn-Tucker conditions, assume that gas is imported at Juárez and exported at Burgos.

There are three cases to study. First, the case when the second arbitrage point is in the Ciudad Pemex-Los Ramones segment (C-R). Second, when the second arbitrage point is north of Los Ramones. Third, the case when the second arbitrage point is at Los Ramones.

⁶If these distributions have mass points as well as segments where demand is zero, small changes in demand can result in large changes in the location of the arbitrage point. This may create incentives for Pemex to reduce or divert production from fields in the south of Mexico. See Brito, Littlejohn and Rosellon (1999).

4. Case I

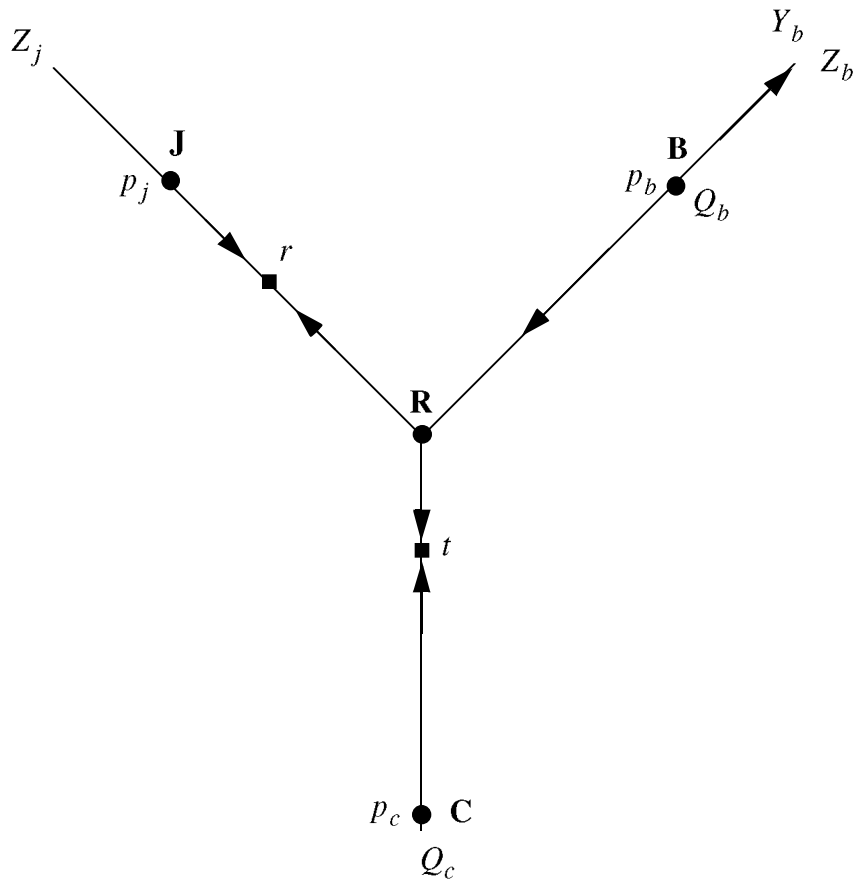


Figure 3

Suppose one of the arbitrage point is in the Juárez-Los Ramones segment of the pipeline and the second arbitrage point is in the Ciudad Pemex-Los Ramones segment. (See Figure 3). The choice variables are exports, Y_b , imports Z_j and the arbitrage points, r and t . The variables of interest are the arbitrage points and the price of gas at Burgos and Ciudad Pemex.

On the Juárez-Los Ramones segment, the cost of moving natural gas from point **J** to a point located at n is $c_J n$ and the cost of moving natural gas from point **R** to a point located at n is $c_J(1-n)$. The cost of moving natural gas from Burgos to Los Ramones is c_b . The cost of moving natural gas from Burgos to a point in the Ciudad Juárez-Los Ramones segment located at n is $c_b + c_J(1-n)$. On the Ciudad Pemex-Los Ramones segment, the

cost of moving natural gas from point **R** to a point located at n is $c_c n$ and the cost of moving natural gas from point **C** to a point located at n is $c_c(1-n)$. The cost of moving natural gas from Burgos to a point in the Ciudad Pemex-Los Ramones segment located at n is $c_b + c_c n$.

The objective function of our model is

$$\begin{aligned} \min \quad & \int_0^r f(n)c_J n dn + \int_r^1 f(n)[c_b + c_J(1-n)]dn + \int_0^t h(n)(c_b + c_c n)dn \\ & + \int_t^1 h(n)[c_c(1-n)]dn + p_j Z_j - p_b Y_b \end{aligned} \quad (1)$$

the constraints are:

$$\int_r^1 f(n)dn + \int_0^t h(n)dn + \int_0^1 g(n)dn + Y_b - Q_b = 0, \quad (2)$$

$$\int_0^r f(n)dn - Z_j = 0, \quad (3)$$

$$\int_t^1 h(n)dn - Q_c = 0 \quad (4)$$

where equation (2) is the resource constraint at Burgos, equation (3) is the resource constraint at Juárez and equation (4) is the resource constraint at Ciudad Pemex. The

Lagrangian is

$$\begin{aligned}
L = & \int_0^r f(n)c_J n dn + \int_r^1 f(n)[c_b + c_J(1-n)]dn + \int_0^t h(n)(c_b + c_c n)dn \\
& + \int_1^0 h(n)[c_c(1-n)]dn + p_J Z_J - p_b Y_b \\
& + \left[\int_r^1 f(n)dn + \int_0^t h(n)dn + \int_0^1 g(n)dn + Y_b - Q_b \right] + \left[\int_0^r f(n)dn - Z_J \right] \\
& + \left[\int_t^1 h(n)dn - Q_c \right]
\end{aligned} \tag{5}$$

where λ is the dual associated with the value of natural gas at Burgos, μ is the dual associated with the imports of natural gas at Juárez and ν is the dual associated with the value of natural gas at Ciudad Pemex. For interior solutions, the first order conditions with respect to Y_b and Z_J are

$$p_b = \lambda \tag{6}$$

$$p_J = \mu \tag{7}$$

The first order conditions with respect to r and t under the assumption that $0 < r < 1$ and $0 < t < 1$ can be written as

$$c_J r - [c_b + c_J(1-r)] - \lambda + \mu = 0. \tag{8}$$

$$(c_b + c_c t) - c_c(1-t) + \lambda - \mu = 0 \tag{9}$$

Equations (6) and (7) determine the price of gas at Burgos and Juárez. Substituting equation (6) into equation (9) gives the price of gas at Ciudad Pemex

$$= p_b + c_b + 2c_c t - c_c \tag{10}$$

The value of t is obtained by solving equation (4).

Substituting equations (6) and (7) into equation (8) gives the arbitrage point on the Juárez- Los Ramones segment of the pipeline

$$r = \frac{(c_b + c_J + p_b - p_J)}{2c_J} \quad (11)$$

Note that if one of the arbitrage points is between Ciudad Pemex and Los Ramones, then the arbitrage point located on the Juárez- Los Ramones-Burgos segments depends only on the price of gas at the endpoints and on the cost of moving gas on these two segments of the pipeline. It is independent of the production at Burgos. The pipeline connecting Burgos, Los Ramones and Juárez is essentially part of the Texas pipeline network.

5. Case II

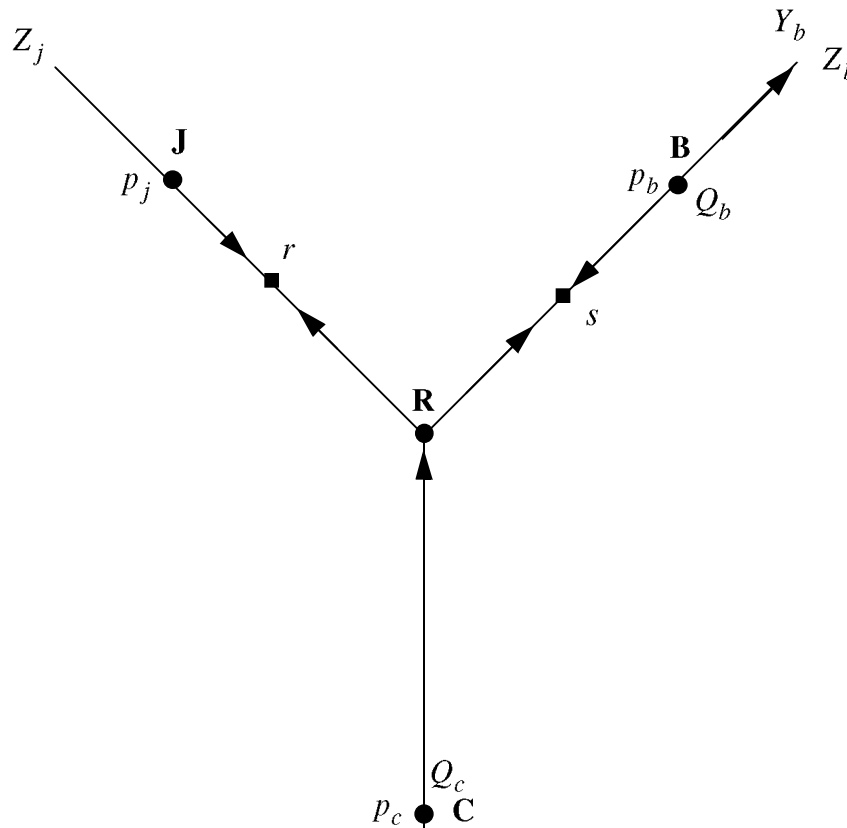


Figure 4

Suppose one of the arbitrage point is in the Juárez-Los Ramones segment of the pipeline and the second arbitrage point is in the Burgos-Los Ramones segment. (See Figure 4). The choice variables are imports Z_j , exports, Y_b and the arbitrage points, r and s . The variables of interest are the arbitrage points and the price of gas at Burgos and Ciudad Pemex.

The objective function of our model is

$$\begin{aligned} \min \quad & \int_0^r f(n)c_j n dn + \int_r^1 f(n)[c_c + c_j(1-n)]dn + \int_0^s g(n)c_b n dn \\ & + \int_s^1 g(n)[c_c + c_b(1-n)]dn + p_j Z_j - p_b Y_b \end{aligned} \quad (12)$$

the constraints are:

$$Q_b - \int_0^s g(n)dn - Y_b = 0, \quad (13)$$

$$\int_0^r f(n)dn - Z_j = 0, \quad (14)$$

$$\int_r^1 f(n)dn + \int_s^1 g(n)dn + \int_0^1 h(n)dn - Q_c = 0 \quad (15)$$

where equation(13) is the resource constraint at Burgos, equation (14) is the resource constraint at Juárez and equation (15) is the resource constraint at Ciudad Pemex. The

Lagrangian is

$$\begin{aligned}
L = & \int_0^r f(n)c_J n dn + \int_r^1 f(n)[c_c + c_J(1-n)]dn + \int_0^s g(n)c_b n dn \\
& + \int_0^1 g(n)[c_c + c_b(1-n)]dn + p_j Z_j - p_b Y_b + \left[\int_0^s g(n)dn + Y_b - Q_b \right] \\
& + \left[\int_0^r f(n)dn - Z_j \right] + \left[\int_r^1 f(n)dn + \int_s^1 g(n)dn + \int_0^1 h(n)dn - Q_c \right]
\end{aligned} \tag{16}$$

For interior solutions, the first order conditions with respect to Y_b and Z_j are

$$p_b = \tag{17}$$

$$p_j = \tag{18}$$

The first order conditions with respect to r and s under the assumption that $0 < r < 1$ and $0 < s < 1$ can be written as

$$c_J r - [c_c + c_J(1-r)] - \dots = 0. \tag{19}$$

$$c_b s - [c_c + c_b(1-s)] + \dots = 0 \tag{20}$$

Substituting equations (17) and (18) into equation (19) together with the resource constraint associate with gas from Ciudad Pemex, gives the arbitrage points and the price of gas at Ciudad Pemex. If we substitute equation (17) into equation (20) we see that the price of gas at Ciudad Pemex is the netback rule,

$$= p_b + c_b s - [c_c + c_b(1-s)] \tag{21}$$

6. Case III

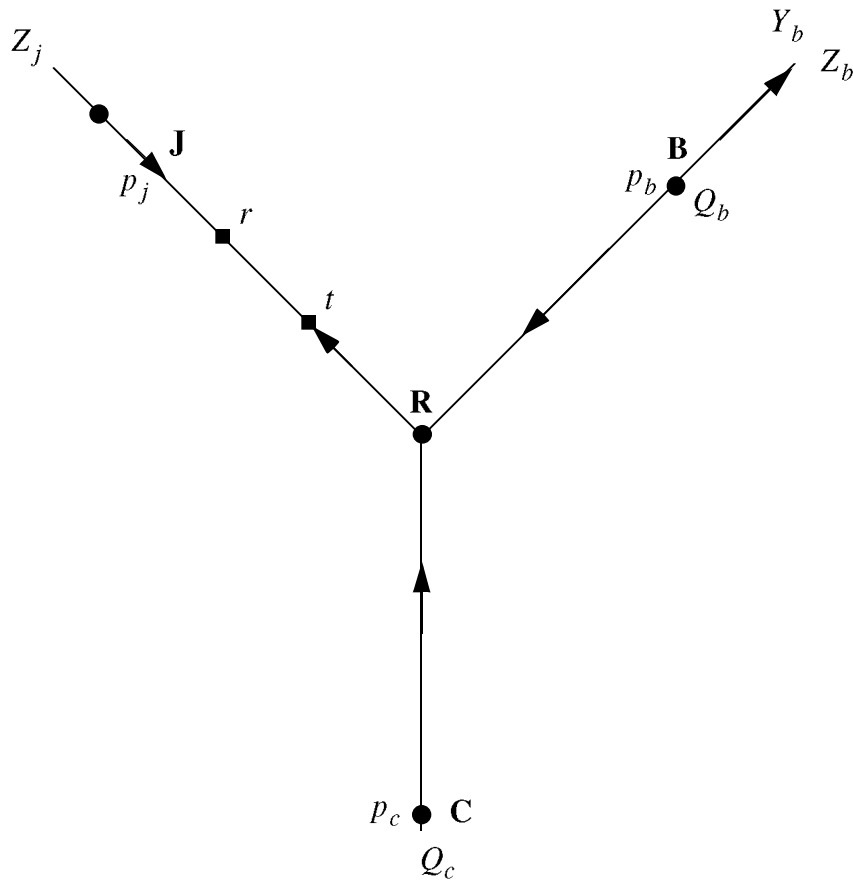


Figure 5

In Case III gas from Burgos and Ciudad Pemex go to the Juárez-Los Ramones segment of the pipeline (See Figure 5). This may be the most important case as it reflects current conditions and will remain so in the foreseeable future. Thus, although this case can be treated as the limit of the first two cases, a careful treatment is justified. Intuitively, it is obvious that the price at Los Ramones is the price at Burgos plus the cost of transportation. The price at Ciudad Pemex is the price at Los Ramones less the cost of transportation. Thus, the price at Ciudad Pemex is the price at Burgos plus the cost of transportation from Burgos to Los Ramones less the cost of transportation from Los Ramones to Ciudad Pemex. If we examine equation (10) for $t = 0$, we get,

$$p_c = p_b + c_b - c_c. \quad (22)$$

It is necessary to solve the problem completely in order to use the model to analyze policy options. To do so, it is useful to use the mathematical fiction that gas from Burgos and Ciudad Pemex are segregated. We will assume that the gas from Ciudad Pemex is delivered to the segment t -R of the Juárez-Los Ramones segment of the pipeline at a cost $c_c + (1 - n)c_J$. The gas from Burgos is delivered to the r - t segment of the Juárez-Los Ramones segment of the pipeline at a cost $c_b + (1 - n)c_J$. (See Figure 5).

The objective function of our model is

$$\begin{aligned} \min \quad & \int_0^r f(n)c_J n dn + \int_r^t f(n)[c_b + c_J(1 - n)]dn \\ & + \int_t^1 f(n)[c_c + c_J(1 - n)]dn + p_j Z_j - p_b Y_b \end{aligned} \quad (23)$$

the constraints are:

$$\int_r^t f(n)dn + D_{br} + Y_b - Q_b = 0, \quad (24)$$

$$\int_0^r f(n)dn - Z_j = 0, \quad (25)$$

$$\int_t^1 f(n)dn + \int_0^1 h(n)dn - Q_c = 0 \quad (26)$$

where equation(24) is the resource constraint at Burgos, equation (25) is the resource constraint at Juárez and equation (26) is the resource constraint at Ciudad Pemex. The Lagrangian is

$$\begin{aligned}
L = & \int_0^r f(n)c_j n dn + \int_0^t f(n)[c_b + c_j(1-n)]dn \\
& + \int_0^1 f(n)[c_c + c_j(1-n)]dn + p_j Z_j - p_b Y_b + \left[\int_r^t f(n)dn + \int_0^1 g(n)dn + Y_b - Q_b \right] \\
& + \left[\int_0^r f(n)dn - Z_j \right] + \left[\int_t^1 f(n)dn + \int_0^1 h(n)dn - Q_c \right]
\end{aligned} \tag{27}$$

For interior solutions, the first order conditions with respect to Y_b and Z_j are

$$p_b = \tag{28}$$

$$p_j = \tag{29}$$

The first order conditions with respect to r and t under the assumption that $0 < r < 1$ and $0 < t < 1$ can be written as

$$c_j r - [c_b + c_j(1-r)] - \dots = 0. \tag{30}$$

$$c_b - c_c + \dots = 0 \tag{31}$$

Note that equation (30) is the same as equation (8) and equation (31) is equation (9) for $t = 0$.

7. Tariff on Natural Gas

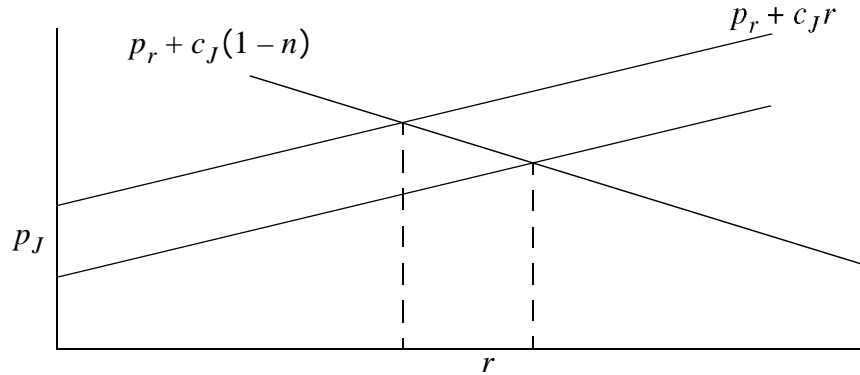


Figure 6

The question of the impact of reducing the import tariff, T , on gas on the price and consumption of gas was part of the policy discussions related to the linking of the Mexican market to the North American market. This model permits us to address this question. If Case I holds, the arbitrage point on Juárez -Los Ramones segment of the pipeline depends only on the production at Ciudad Pemex. The arbitrage point on Juárez -Los Ramones segment of the pipeline is determined by equation (11). Differentiating equation (11) with

respect to T and noting that $\frac{dp_J}{dT} = 1$, then

$$\frac{dr}{dp_J} = \frac{-1}{2c_J} < 0 \quad (32)$$

A decrease in the price at Juárez will increase the value of r and thus move the arbitrage point south. The price at Ciudad Pemex is linked to the price at Burgos and remains unchanged. (See equation (10)) Since the demand on the Los Ramones-Ciudad Pemex segment has not changed, the gas balance is maintained by increasing exports at Burgos. Imports at Juárez are offset by exports at Burgos. The price of gas for points north of the Juárez -Los Ramones arbitrage point will drop; the price of gas for points south of the Juárez -Los Ramones arbitrage point will not change. (See Figure 6.) The analysis for Case III is similar.

If Case II holds and gas is being imported at Juárez and exported at Burgos we can differentiate equations (15), (19) and (20) with respect to p_J (See Appendix) and solve the resulting linear system to get

$$\frac{dr}{dT} = \frac{-g(s)}{2[g(s)c_J + f(r)c_b]} < 0 \quad (33)$$

$$\frac{ds}{dT} = \frac{f(r)}{2[g(s)c_J + f(r)c_b]} > 0 \quad (34)$$

$$\frac{dp_r}{dT} = \frac{c_b f(r)}{[g(s)c_J + f(r)c_b]} > 0 \quad (35)$$

This implies that a decrease in the price at Ciudad Juárez would move the arbitrage point south on the Juárez- Los Ramones segment of the pipeline and north on the Burgos- Los Ramones segment of the pipeline. The price at Los Ramones would go down. The increase in imports from Juárez is offset by an increase in exports at Burgos. By moving the arbitrage point north on the Burgos-Los Ramones segment of the pipeline, a decrease in the price at Ciudad Juárez would decrease the price of gas in Mexico. The amount of gas imports does not change as the real net effect is to move gas from West Texas to the Houston market.

In all the three cases if gas is being imported both at Burgos and Juárez, a reduction of the tariff would not change the arbitrage points since the arbitrage points are a function of the difference in prices and this difference does not change. There would be no change in imports, but the price at Ciudad Pemex would drop by the amount of the tariff through the netback rule. (See Appendix.)

8. Export Constraints

This analysis was done under the assumption that the export of gas at Burgos was not constrained by pipe capacity. If these flows are constrained, then it is necessary to add

a constraint, \bar{Y}_b , for exports at Burgos and a constraint, \bar{Z}_J , for imports at Juárez to the minimization problem. These can be written as

$$\bar{Y}_b - Y_b = 0 \quad (36)$$

$$\bar{Z}_J - Z_J = 0 \quad (37)$$

First, let us consider the case when the constraint on exports at Burgos is binding. The first order condition is

$$= p_b - \lambda_b, \quad (38)$$

where λ_b is the Lagrange multiplier for the export constraint. Mexico's linkage with the United States gas market would be the price at Ciudad Juárez through

$$= p_J \quad (39)$$

Applying the netback rule, the price at Los Ramones is

$$p_r = p_J + 2c_J r - \frac{1}{2} \quad (40)$$

The price at Burgos would in turn be determined by the price at Los Ramones and the cost of moving gas from Burgos to Los Ramones,

$$p_b = p_J + 2c_J r - \frac{1}{2} - c_b \quad (41)$$

The differential between the price at Burgos and the Houston Ship Channel price (adjusted) would be reflected in the Lagrange multiplier associated with the capacity constraint on exports, λ_b .

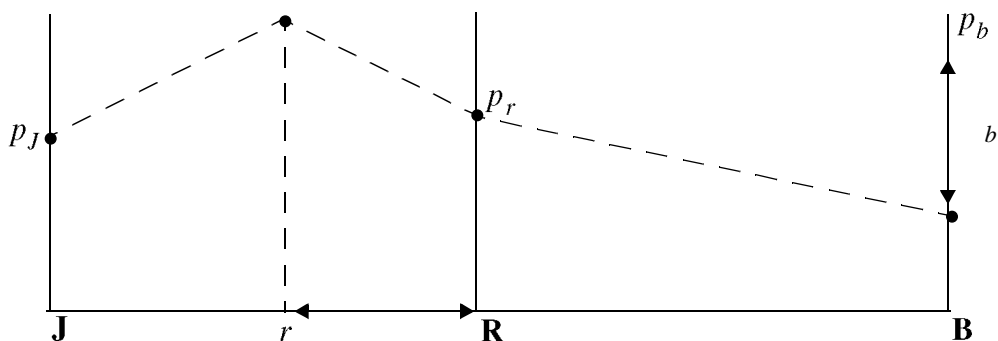


Figure 7

The arbitrage points, r and t , would be determined by the relations

$$Q_c = \int_t^1 h(n)dn, \quad (42)$$

$$Q_b - \bar{Y}_b = \int_0^t h(n)dn + \int_r^1 f(n)dn + \int_0^1 g(n)dn. \quad (43)$$

The analysis for the other cases is similar. As long as the link between the arbitrage point is not constrained, the price at Ciudad Juárez will be a reasonable guide as the North American gas market is likely to be in equilibrium. It may be the case, however, that demand conditions are such that the pipeline system in the United States is not able to move sufficient gas to reach a market equilibrium. West Texas gas may be underpriced and this will be reflected in the price of gas in Mexico.

The pipeline from Ciudad Juárez to the West Texas fields has limited capacity and it is possible that both constraints may bind. If the constraint for the supply of gas at Burgos given by (2) is not binding, then that dual, λ , is equal to zero. The arbitrage point on the Juárez-Los Ramones segment is determined by the import constraint,

$$\bar{Z}_J = \int_0^r f(n)dn \quad (44)$$

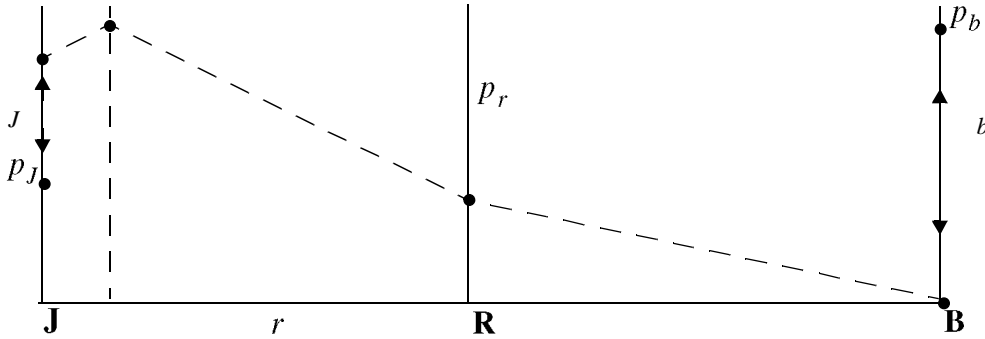


Figure 8

9. Location of Production

Another issue that has come up in policy discussion is the impact of the distribution of gas production on the price of gas in Mexico. Some people were surprised that the large discoveries at Burgos did not lower the price of gas in Mexico. However, if we examine the equations that determine the price of gas in Mexico in the three important cases we have studied the production of gas at Burgos does not play a role. It is only if exports at Burgos are constrained by capacity that the level of production at Burgos has any impact on the price of gas in Mexico. In the absence of export constraints, the marginal gas produced is exported.

A related question is whether there are any welfare implications associated with the location of production or new discoveries. This question is easily answered by examining the duals for production at Burgos and Ciudad Pemex. Recall that the economic interpretation of the dual is the value of relaxing that constraint. The value of the dual at Burgos is

$$= p_b \quad (45)$$

and the value of the dual at Ciudad Pemex is

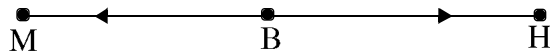
$$= p_b + c_b + 2c_c t - c_c \quad (46)$$

If the term $c_b + 2c_c t - c_c$ is positive it is more efficient to develop gas resources at Ciudad Pemex, if the term $c_b + 2c_c t - c_c$ is negative it is more efficient to develop gas resources at Burgos. The intuition behind this result is simple. Let t be the distance from Ciudad Pemex to the arbitrage point. The cost of moving a unit of gas from Ciudad Pemex to the arbitrage point is $(1-t)c_c$. The cost of moving a unit of gas from Burgos to the arbitrage point is $c_b + tc_c$. If a unit of gas is produced at Burgos it is sold at a price p_b . If a unit of gas is produced at Ciudad Pemex it displaces a unit at the arbitrage point which releases a unit at Burgos which is sold at a price p_b . The net benefit of a marginal unit of production is

$$- = p_b - [p_b - (1-t)c_c + (c_b + tc_c)] = c_c - c_b + 2tc_c \quad (47)$$

The production at the point nearest the arbitrage point yields the highest net social benefit. It should be noted that if there is some flexibility in meeting domestic demands from Burgos or Ciudad Pemex, revenue maximizing behavior on the part of Pemex would shift production to Ciudad Pemex.

10. Forward Markets and Pipeline Capacity



The regulations the CRE has issued requires that Pemex sell gas on the spot market at the Houston Ship Channel price, adjusted by the netback rule. The question then occurs whether Pemex can use its monopoly power over the pipeline to get monopoly rent in this forward market. To address this question let us consider a simple model. Assume a two pe-

riod model. Gas is produced at Burgos and shipped to Houston and Monterrey. Let p_i be the spot price at time t in market i and \hat{p}_i be the forward price at time 0 in market i ; p_{0h} is the spot price at Houston a time 0, p_{0m} is the spot price at Monterrey at time 0. Prices at time 1 and forward price are defined in a similar fashion. Let c_h be the cost of moving gas from Burgos to Houston, c_m be the cost of moving gas from Burgos to Monterrey, and $c = c_m - c_h$. Let \bar{Q}_m be the capacity constraint on the pipeline from Burgos to Monterrey. If the capacity constraint does not bind, the price at Monterrey is $p_m = p_h + c$. (See Figure 9 left) If the capacity constraint binds, the price at Monterrey is $p_m = p_h + c + p$, where p are the rents associated with the capacity constraint. (See Figure 9 right)

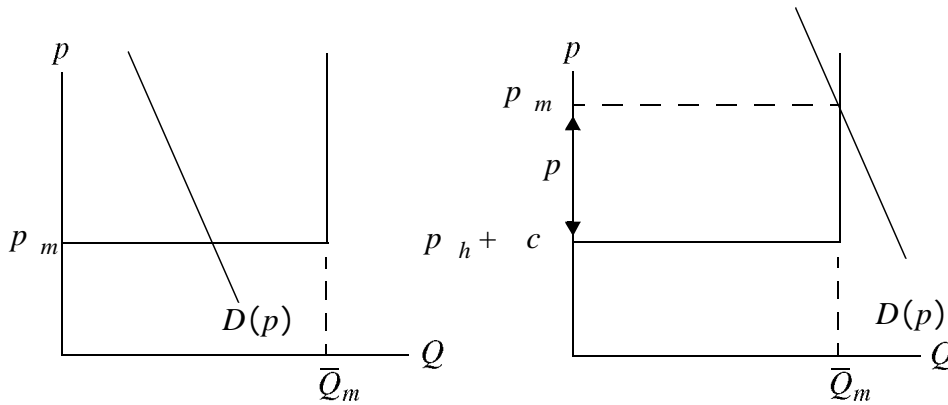


Figure 9

If the capacity constraint on the pipeline is not binding, the spot market price in Monterrey will be $p_m = p_h + c$. Anyone who desires to engage in forward transactions can do so in the Houston market. Pemex does not have an effective monopoly of the forward market and will capture no rents.

Suppose the capacity constraint on the pipeline is always binding and the price differential is constant, \bar{p} . In that case the spot market price in Monterrey will be

$p_m = p_h + c + \bar{p}$. Anyone who desires to engage in forward transactions can do so in the Houston market. However, Pemex can capture the rents associated with the pipeline constraint by selling output forward. Note that rents will exist and the only question is who will appropriate them. Given that the capacity constraint on the pipeline is binding, there are no real effects.

Now suppose the capacity constraint on the pipeline is binding with a probability q and the price differential is constant, \bar{p} . In that case the spot market price in Monterrey will be $p_m = p_h + c + \bar{p}$ with a probability q and $p_m = p_h + c$ with a probability $(1 - q)$. The equilibrium forward price of gas will be

$$\hat{p}_m = q(p_h + c + \bar{p}) + (1 - q)(p_h + c) \quad (48)$$

Anyone who desires to engage in forward transactions can do so in the Houston market. However, Pemex can capture the rents associated with the pipeline constraint by selling output forward. If the pipeline capacity constraint is binding, rents will exist and the only question is who will appropriate them.

The key regulatory issue in this context appears to be insuring that Pemex invests sufficiently in pipeline capacity so that capacity constraints are not a serious issue. However, a complete study of this issue is beyond the scope of this paper.

11. Conclusions

This paper studies the implications of linking the Mexican market for natural gas to the North American market. We construct a mathematical model of the Mexican natural gas pipeline network and use it to analyze various policy questions. We show that the net-back rule is the only efficient way to price natural gas in a static context. In a static model this price rule would be optimum. However, two equilibrium conditions have to be satisfied for efficiency: spatial and intertemporal conditions. In the spatial market, the price of natural gas must be linked to transport costs while in the intertemporal market the price of natural gas at any two points in time should be linked by the interest rate and the cost of

holding natural gas. A rule that achieves the first best is not feasible. Further, there are two factors that mitigate the intertemporal distortions. First, gas is the dominant technology in the generation of electricity. This is one of the most important use of gas and the fluctuations in the price are not likely to distort the choice of technology. Second, a broad market in future contracts is emerging. This market enables gas consumers in Mexico to hedge against some of the risk created by the weather in the United States.

The import tax on gas to the Mexican gas market was recently eliminated. We show that if gas is being imported at Juárez and exported at Burgos, the reduction in the tax will result in no net changes in gas imports or exports. There will be no change in the price of domestically produced gas. If gas is being imported both at Juárez and Burgos, the reduction in the tax will result in no changes in gas imports or exports and the price of gas in Mexico is reduced by the amount of the tax.

We study the welfare implications of the location of investment in new gas production and show that it is optimal to invest in the source closest to the arbitrage point rather than to the center of consumption. This suggests that the decision to invest in development of gas fields near Burgos is correct.

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Appendix

This appendix derives the impact of a reduction in the import tariff for natural gas for the case where both arbitrage points are north of Los Ramones. The first order conditions from the maximization problem are

$$2c_J r - [c_c + c_J] - p_c = -p_J \quad (\text{A-1})$$

$$2c_b s - [c_c + c_b] - p_c = -p_b \quad (\text{A-2})$$

$$\int_r^1 f(n)dn + \int_s^1 g(n)dn = Q_c - \int_0^1 h(n)dn \quad (\text{A-3})$$

Case A: Gas is only imported at Ciudad Juárez

Let T be the tariff. If gas is only imported at Ciudad Juárez, we can differentiate with respect to T and $\frac{dp_J}{dT} = 1$ then

spect to T and $\frac{dp_J}{dT} = 1$ then

$$\begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & -1 \\ -f(r) & -g(s) & 0 \end{bmatrix} \begin{bmatrix} dr \\ ds \\ dp_c \end{bmatrix} = \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \quad (\text{A-4})$$

where $dr = \frac{dr}{dT}$, $ds = \frac{ds}{dT}$, and $dp_c = \frac{dp_c}{dT}$. If we use Cramer's rule,

$$\det \begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & -1 \\ -f(r) & -g(s) & 0 \end{bmatrix} = -2c_J g(s) - 2f(r)c_b = -2[g(s)c_J + f(r)c_b] \quad (\text{A-5})$$

$$\det \begin{bmatrix} -1 & 0 & -1 \\ 0 & 2c_b & -1 \\ 0 & -g(s) & 0 \end{bmatrix} = g(s) \quad (\text{A-6})$$

$$\det \begin{bmatrix} 2c_J & -1 & -1 \\ 0 & 0 & -1 \\ -f(r) & 0 & 0 \end{bmatrix} = -f(r) \quad (\text{A-7})$$

$$\det \begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & 0 \\ -f(r) & -g(s) & 0 \end{bmatrix} = -2c_b f(r) \quad (\text{A-8})$$

$$\frac{dr}{dT} = \frac{g(s)}{-2[g(s)c_J + f(r)c_b]} = \frac{-g(s)}{2[g(s)c_J + f(r)c_b]} \quad (\text{A-9})$$

$$\frac{ds}{dT} = \frac{-f(r)}{-2[g(s)c_J + f(r)c_b]} = \frac{f(r)}{2[g(s)c_J + f(r)c_b]} \quad (\text{A-10})$$

$$\frac{dp_c}{dT} = \frac{-2c_b f(r)}{-2[g(s)c_J + f(r)c_b]} = \frac{c_b f(r)}{[g(s)c_J + f(r)c_b]} \quad (\text{A-11})$$

Case B: Gas is imported at Burgos and Ciudad Juárez

If gas is only imported at Burgos and Ciudad Juárez, we can differentiate with respect to T ,

$\frac{dp_J}{dT} = 1$ and $\frac{dp_J}{dT} = 1$. Then

$$\begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & -1 \\ -f(r) & -g(s) & 0 \end{bmatrix} \begin{bmatrix} dr \\ ds \\ dp_c \end{bmatrix} = \begin{bmatrix} -1 \\ -1 \\ 0 \end{bmatrix} \quad (\text{A-12})$$

$$\det \begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & -1 \\ -f(r) & -g(s) & 0 \end{bmatrix} = -2c_J g(s) - 2f(r)c_b = -2[g(s)c_J + f(r)c_b] \quad (\text{A-13})$$

$$\det \begin{bmatrix} -1 & 0 & -1 \\ -1 & 2c_b & -1 \\ 0 & -g(s) & 0 \end{bmatrix} = g(s) - g(s) = 0 \quad (\text{A-14})$$

$$\det \begin{bmatrix} 2c_J & -1 & -1 \\ 0 & -1 & -1 \\ -f(r) & 0 & 0 \end{bmatrix} = 0 \quad (\text{A-15})$$

$$\det \begin{bmatrix} 2c_J & 0 & -1 \\ 0 & 2c_b & -1 \\ -f(r) & -g(s) & 0 \end{bmatrix} = -2[g(s)c_J + f(r)c_b] \quad (\text{A-16})$$

so

$$\frac{dr}{dT} = 0 \quad (\text{A-17})$$

$$\frac{ds}{dT} = 0 \quad (\text{A-18})$$

$$\frac{dp_c}{dT} = 1 \quad (\text{A-19})$$