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Modeling and Optimizing the Midstream of China's Natural Gas Industry

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Abstract: Gordon *et al.* (2003) tested for subadditivity in the cost structure associated with transporting natural gas by Trans-Canada Pipelines Ltd. and showed that the subadditivity in gas transmission cost was evident and consequently, the possible benefits from increased competition resulting from splitting up the monopoly could be offset by the sacrifice of scale efficiencies. This paper outlined a proposal of natural gas pipeline integration and then justified this proposition applying the theory of economics. Because the natural gas pipeline is of natural monopoly and the up-stream of the natural gas industry in China is of oligopoly competition, separated from the gas producers, the pipeline integration will change the competition equilibrium of the up-stream market. Based on a series of assumptions, this paper conducted an oligopoly competition model of the natural gas market in China, under the framework of which the proposed integration was analyzed concerning the influences this change would bring and thereafter the end of this paper concluded that the pipeline integration is beneficial for Chinese gas producers as well as consumers and helps promote the social benefits as a whole.

Key words: Natural gas, industry, natural monopoly, cournot model

INTRODUCTION

It's hard to track the "pipeline integration" literarily, for the call for "integration" has not been publicly delivered, though frequently talked about both inside and outside the oil and gas industrial circle. The only exception, if any, may be the answers given by some experts during a media interview after the National Development and Reform Commission's workshop conference on the natural gas price, held in Chengdu, May 2007. However, the concept "pipeline integration" has not been further developed, nor clearly defined.

Presently, the two giant monopolies, Petro China and Sinopec own almost all the natural gas pipelines in the mainland, with the rough proportions, 90 and 10% respectively. Each party's pipeline assets are independent from others' and a nationally integrated pipeline network has not yet formed. Because the two monopolists are competitors and there is no up-down relationship between them within the natural gas business scope, the proposed "integration" would be a horizontal (or lateral) one, which is expected to operate as a natural monopoly independent from the parent entities. There is no doubt that the integration must be enforced by the government and a special permission should be assigned to it. The integrated monopoly will be fully in charge of the natural gas pipeline planning, construction, operation and mediation. Under government regulation, the gas

transmission price is assumed to be determined under the marginal cost rule.

The natural gas pipeline, also called the middle stream of the natural gas industry, is the vital connection between the up-stream and the down-stream and the key infrastructure enabling the marketing of the gas from wells. What changes the proposed integration would bring and whether the outcomes would be favorable for stakeholders and beneficial for the society as a whole? The following parts will answer this question by comparing the ex-ante and the ex-post outcomes under the framework of the oligopolistic competition model.

THE NATURAL MONOPOLY PROPERTY OF THE GAS PIPELINE

Subadditivity is, generally, a necessary and sufficient condition for the verification of a natural monopoly (Baumol, 1977; Boettke, 1994). In economics, subadditivity represents economics of scale. Inspired by the way many prior efforts to test for subadditivity in telephone industry (Babe, 1990; Evans and Heckman, 1984). (Gordon *et al.*, 2003) also tested for subadditivity in the cost structure associated with transporting natural gas by Trans-Canada Pipelines Ltd, finding that the subadditivity in gas transmission cost was evident and consequently the possible benefits from increased competition resulting from splitting up the monopoly could be offset by the

sacrifice of scale efficiencies. (Fengling, 2005; Dan, 2007) also pointed out that the middle stream gas pipelines in China's mainland are of natural monopoly.

It is for the the natural gas pipeline's natural monopoly property that the pipeline integration will change the gas transmission cost function and consequently change the natural gas market structure essentially. Now, CNPC (China National Petroleum Company) possesses the vast majority of the pipelines and therefore takes the obvious advantage of scale efficiency over Sinopec (China Petrochemical Corporation). This will be recognized as a presumed condition in the modeling analysis dominating the remaining parts of this paper.

THE OLIGOPOLISTIC MODEL OF CHINA'S NATURAL GAS MARKET

The oligopolistic competition of the natural gas market in China has been soundly elaborated in the book *The Path Way of The Oil Industry Development in China: Oligopolistic Competition and Regulation*, so more explanation is not targeted at by this paper. Cournot Model, which is classic in oligopoly analysis and appears less controversial than the twin, Bertrand Model (Tirole, 1988), was applied in this paper.

Assumptions:

- To simplify the question, it's assumed that there are only two firms, firm1 and firm 2, which supply natural gas at the up-stream level. Firm 1 and Firm 2 transport their gas through the pipelines of themselves before the pipeline integration; the gas provided by the two firms is seen as homogeneous and the gas reserved for extraction is enough
- The marginal transmission cost functions of each firm are continuous and at least first-order derivable; firm 1 owns much more pipelines, so it has larger scale efficiency, which means, given the same transmission quantities, the marginal cost of firm 1 is less than that of firm 2 and the marginal cost of firm 1 decreases quicker than firm 2 as the transmission quantity increases. This is common knowledge for the two firms and, is illustrated by Fig. 1. MC_1 represents firm1's marginal cost curve while MC_2 represents firm 2's. If the marginal cost is denoted as a function of output q realized by pipeline transmission, the two curves satisfy: $MC_1(q) < MC_2(q)$ and $MC'_1(q) < MC'_2(q)$.
- The two firms face the same reversed demand

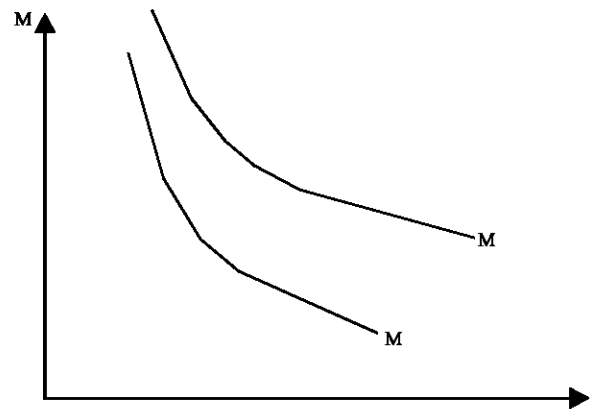


Fig. 1: The marginal cost curves of two natural monopolies with different scales

$$P = a - bQ$$

where P stands for the price for which gas is sold at the end of the pipeline and Q the total volume of gas demanded at the end of the pipeline; $a > 0$, $b > 0$

- The two firms determine q_1 and q_2 simultaneously and conspiracy of the two is not desirable..
- Gas inventory is neglected

The model: Set π_1 as firm 1's profit, π_2 firm 2's profit, $C_1(q)$ firm 1's cost function and $C_2(q)$ firm 2's cost function. Then, firm 1's optimizing choice is:

$$\max_{q_1} \pi_1 = [a - b(q_1 + a_2)]a_1 - C_1(q_1) \quad (1)$$

The solution's first-order condition is: $\pi'_1 = -bq_1 + a - bq_2 - MC_1(q_1) = 0$ and further:

$$-2bq_1 - bq_2 + a = MC_1(q_1) \quad (2)$$

Similarly, firm 2's optimizing choice is :

$$\max_{q_2} \pi_2 = [a - b(q_1 + a_2)]a_2 - C_2(q_2) \quad (3)$$

And the corresponding first-order condition is:

$$-2bq_2 - bq_1 + a = MC_2(q_2) \quad (4)$$

Combining Eq. 2 and 4 produces the equation set:

$$\begin{cases} -2bq_1 - bq_2 + a = MC_1(q_1) \\ -2bq_2 - bq_1 + a = MC_2(q_2) \end{cases} \quad (5)$$

which outlines the oligopolistic competition of the natural gas market in the mainland of China.

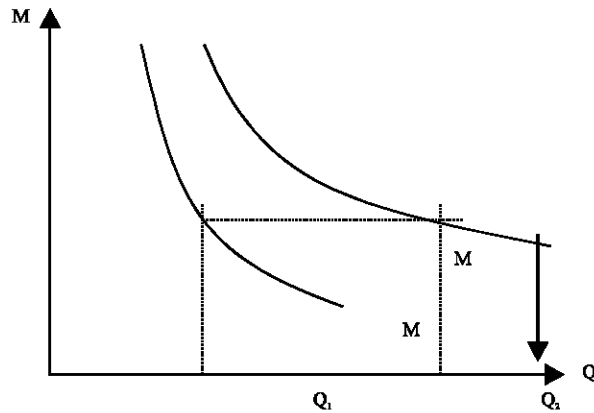


Fig. 2: When $q_1 < q_2$, Nash Equilibrium at least requires $q_1 < Q_1$ and $q_2 > Q_2$

The equilibrium: From equation set (5), we can obtain:

$$b(q_2 - q_1) = MC_1(q_1) - MC_2(q_2) \quad (6)$$

Planting Eq. 6 into 2 will result in:

$$q_1^* = \frac{a + MC_2(q_2) - 2MC_1(q_1)}{3b} \quad (7)$$

and, planting Eq. 7 into 4 will result in:

$$q_2^* = \frac{a + MC_1(q_1) - 2MC_2(q_2)}{3b} \quad (8)$$

Equation 7 and 8 is the equilibrium solution before the pipeline integration.

In Eq. 6, if $q_1 = q_2$, the right side of the equation must equals zero. But Fig. 1 shows that $MC_1(q_1) < MC_2(q_2)$, which means the right side of equation (6) is smaller then zero. Thus, $q_1 \neq q_2$; if $q_1 < q_2$, then $MC_1(q_1) > MC_2(q_2)$ must holds and as a necessary condition, $q_1 < Q_1$ and $q_2 > Q_2$ must hold simultaneously. However, it's not firm 1's dominant strategy to select a transmission volume less than Q_1 when firm 2's marginal cost is quite obviously in a less favorable situation. Thus, by method of exclusion, $q_1 > q_2$ (or $q_1^* > q_2^*$) is obtained, which means firm 1 transports more gas than firm 2 and the market's total transmission volume is:

$$Q^* = q_1^* + q_2^* = \frac{2a - MC_1(q_1) - MC_2(q_2)}{3b} \quad (9)$$

EFFECTS OF THE PIPELINE INTEGRATION

The "integration" proposition also includes the regulating rule that the transmission price is determined according to the marginal cost-pricing rule. Therefore, the

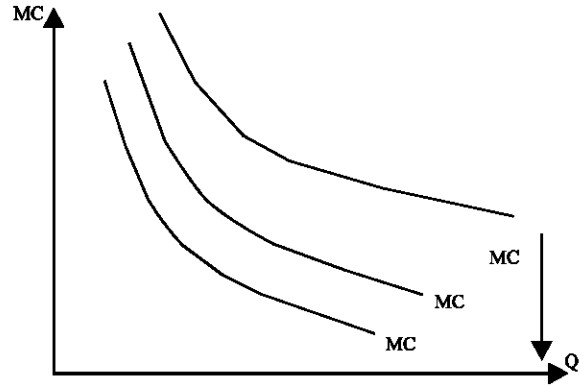


Fig. 3: The changes of the marginal cost curves bought by the pipeline integration

analysis further assumes that this rule is strictly in control. Under this condition, the horizontally integrated pipeline network would make firm 1 and firm 2 have the same transmission cost function and the same marginal transmission cost function as well. The shared common transmission cost function is denoted as $C(q)$, where $MC' q = q_1 + q_2$ and the corresponding marginal cost function shared is denoted as $MC(q) = \partial C / \partial q$, where $MC'(q) < 0$. After integration, the pipeline's scale efficiency would be greater, as illustrated in Fig. 3, both firms' marginal cost would decline to $MC(q)$ or MC for short. The ex-ante and ex-post marginal cost functions satisfy: $MC(q) < MC_1(q) < MC_2(q)$, given the same quantity q .

After "pipeline integration", the new Cournot Model would be:

$$\begin{cases} -2bq_1 - bq_2 + a = \partial C(q_1, q_2) / \partial q_1 \\ -2bq_2 - bq_1 + a = \partial C(q_1, q_2) / \partial q_2 \end{cases} \quad (10)$$

From equation set (10), we can obtain:

$$b(q_2 - q_1) = \partial C(q_1, q_2) / \partial q_1 - \partial C(q_1, q_2) / \partial q_2 \quad (11)$$

Planting Eq. 11 into equation set (10) results in:

$$q_1^* = \frac{a + \partial C(q_1, q_2) / \partial q_2 - 2\partial C(q_1, q_2) / \partial q_1}{3b} \quad (12)$$

$$q_2^* = \frac{a + \partial C(q_1, q_2) / \partial q_1 - 2\partial C(q_1, q_2) / \partial q_2}{3b} \quad (13)$$

Therefore, the total transmission volume after "pipeline integration" would be:

$$Q'^* = q_1^* + q_2^* = \frac{2a - \partial C(q_1, q_2)/\partial q_1 - \partial C(q_1, q_2)/\partial q_2}{3b} \quad (14)$$

Transmission volume change:

- q_1^* and q_2^*

Observing Eq. 11:

If $q_1 < q_2$, then $\partial C(q_1, q_2)/\partial q_1 > \partial C(q_1, q_2)/\partial q_2$ and both the left side and the right side equal zero;

If $q_1 > q_2$, then $\partial C(q_1, q_2)/\partial q_1 < \partial C(q_1, q_2)/\partial q_2$ and both the left side and the right side are smaller than zero;

If $q_1 = q_2$, then $\partial C(q_1, q_2)/\partial q_1 = \partial C(q_1, q_2)/\partial q_2$ and both the left side and the right side equal zero.

The above three outcomes are all possible. An absolutely symmetrical competition between two oligopolies with the same cost function surely results in an absolutely symmetrical equilibrium, of which an important characteristics is the same volumes of outcome. However, no symmetrical competition really exists. Although pipeline assets have been coercively peeled off the parent entities, the firm with a lower marginal cost curve ex-ante may still have other advantages ex-post in fields such as technology, human resources and etc. Therefore, firm 1 may still transport more gas than firm 2 after the "integration", but the volume gap would be narrowed and the scale of this narrowness depends on other costs besides the transmission cost. Other costs are ruled out in this paper and $q_1 = q_2$ is solely considered in the following text.

- The total outcome change

For:

$$Q'^* - Q^* = \frac{(MC_1 - \partial C/\partial q_1) + (MC_2 - \partial C/\partial q_2)}{3b} \quad (15)$$

and $MC_1 > \partial C/\partial q_1$, $MC_2 > \partial C/\partial q_2$, obtain $Q'^* > Q^*$, which means the total outcome would increase.

- q_1^* and q_1' , q_2^* and q_2'

$$q_1 - q_1' = \frac{2(\partial C/\partial q_1 - MC_1) + (MC_2 - \partial C/\partial q_2)}{3b} \quad (16)$$

$$q_2 - q_2' = \frac{2(\partial C/\partial q_2 - MC_2) + (MC_1 - \partial C/\partial q_1)}{3b} \quad (17)$$

Figure 3 shows that both the two firms improve in terms of transmission cost after the pipeline integration and firm 2 improves more, for:

$$\partial C/\partial q_1 - MC_1 < 0 \quad MC_2 - \partial C/\partial q_2 > 0$$

and

$$\left| \partial C/\partial q_1 - MC_1 \right| < \left| \partial C/\partial q_2 - MC_2 \right|$$

It is known by further analysis that, if:

$$\left| \partial C/\partial q_1 - MC_1 \right| < \left| MC_2 - \partial C/\partial q_2 \right|/2$$

then $q_1 > q_1'$, which means firm 1's production would decrease after integration;

If:

$$\left| MC_2 - \partial C/\partial q_2 \right|/2 < \left| \partial C/\partial q_1 - MC_1 \right| < \left| MC_2 - \partial C/\partial q_2 \right|$$

then $q_1 > q_1'$, which means firm 1's production would increase after integration;

In other words, firm 1's production volume change depends on the gap of scale efficiency between the two firms.

Considering firm 2, because:

$$\left| MC_2 - \partial C/\partial q_2 \right|/2 < \left| \partial C/\partial q_1 - MC_1 \right| < \left| MC_2 - \partial C/\partial q_2 \right|$$

then $q_2 < q_2'$, which means firm 2 would increase its production. In addition, $|q_1 - q_1'| < |q_2 - q_2'|$, which means the scale of firm 2's volume change is larger than that of firm 1's.

In fact, if firm 1 and firm 2 represent CNPC (China National Petroleum Company) and Sinopec (China Petrochemical Corporation) respectively:

$$\left| MC_2 - \partial C/\partial q_2 \right|/2 < \left| \partial C/\partial q_1 - MC_1 \right| < \left| MC_2 - \partial C/\partial q_2 \right|$$

will hold and then the pipeline integration would increase both firm 1 and firm 2's production. This is meaningful for the quickly increasing demand for natural gas in China.

Profit change: Profit change becomes more complicated because it depends on the price elasticity of demand and the firms' total cost function. However, associated with the status quo of the natural gas industry in China, a

judgment can be approximately made that, for the natural gas's elasticity of demand is on the low side (Wenping *et al.*, 2007; Zhongjin, 2005), the increase of production is quicker than the decline of price and consequently the sum of the firms' revenue would increase after the pipeline integration. Considering CNPC, its marginal cost would also be improved a lot and then there would be a bigger production volume of which the total cost equals that of a smaller production volume export. Therefore, the total revenue change of CNPC is positive and of course, the profit change of CNPC is positive. The efficiency improvement for Sinopec would be greater, obviously. In all, both the two giant monopolists' profits would increase.

Consumers' surplus change: In this study analysis, the costs not associated with the transmission process were ruled out, the pipeline integration decreases the gas price at the end of the pipelines and increases the total production. Therefore, it means that consumers can use more gas at lower prices. In another saying, the consumers' surplus also increases. What's more, more natural gas means cleaner living condition.

So far, it can be inferred that the natural gas pipeline integration is beneficial for the society as a whole.

CONCLUSION

To summarize, this paper arrives at laudable conclusions as follow:

- The natural gas pipeline integration decreases the gas producers' cost, makes the up-stream of the natural gas industry more competitive and increases gas production
- Every gas producer's profit is expected to increase
- Consumers' surplus is also expected to increase; and
- As a whole, the society benefits from the natural gas pipeline integration in terms of both energy security and "green development"

The analysis paradigm of this paper begins with many assumptions of which some may be found unrealistic, lacks the accuracy of a quantitative approach and needs verifying and improving in further field studies,

though it provides a theoretically reasonable understanding. In this sense, the analysis of this paper is basic.

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