A Game of Upstream Natural Gas Pipeline Development

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January 2008

The upstream natural gas infrastructure development is crucial for the Norwegian natural gas sector. This paper introduces a two player game which describes the competition between two natural gas companies while they are developing new upstream natural gas pipelines. Different Nash Equilibria are demonstrated under different circumstances. Given our assumptions, we observe that tariffs can influence development of new pipelines. Natural gas companies will minimize their new pipelines’ size if they can rely on others’ infrastructure, and the current Norwegian natural gas transportation system may give rise to such situations. Thus, while Norwegian authorities is trying to provide a safe and reliable transportation system, reduced incentives for new infrastructure investments can be the outcome.

1 Introduction

Norwegian natural gas plays an important role in supply of energy in Europe. It is exported to all of the major consumer countries in Western Europe. Norwegian natural gas producers have sales agreements with buyers in Germany, France, the UK, Belgium, the Netherlands, Italy, Spain, the Czech Republic, Austria, Poland, Denmark and Switzerland. In France and German, Norwegian gas supplies around 30 percent of the total consumption. When the Ormen Lange field comes on stream, Norwegian gas will have a market share of approximately 15-20 percent in the United Kingdom.

A particular feature of natural gas industry is the huge sums invested in transportation. Once natural gas has been produced, it has to be transported

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http://gcweb04.gasco.no/sw3132.asp

to markets. Norwegian natural gas is mainly transported by its large submarine pipeline system, which is the most extensive offshore upstream pipeline system in the world. In 2005, this system carried 81.51 billion cubic meters of dry (sales) gas to market, which accounts for approximately 15 percent of European natural gas consumption. Consequently, the upstream infrastructure development is crucial for the Norwegian natural gas sector.

The Norwegian upstream natural gas infrastructure should provide the natural gas producers and customers with necessary transportation capacity. Not only should it ensure the supply of natural gas to the continental Europe and UK, but it must guarantee that the natural gas resources can be fully developed in the Norwegian continental shelf as well. When new production fields are going to be developed, the upstream infrastructure must be available, as a link to the market is required. According to the last annual report of the Norwegian Ministry of Petroleum and Energy, more and more new but smaller developments rely on the existing infrastructure. This interesting trend certainly makes the existing infrastructure and infrastructure development more important in the Norwegian natural gas sector.

The Norwegian natural gas transportation network was owned by a number of oil and gas companies before 2002. Due to the considerable sunk costs of the infrastructure, the natural gas pipeline is a typical natural monopoly. Hence these pipeline owners, usually the large oil and gas companies on Norwegian continental shelf, had some market power over their competitors and other parties without transportation facilities.

The situation changed when a Norwegian state-owned company Gassco took over the operatorship of all natural gas transport from the Norwegian continental shelf on January 1., 2002. One year later, the whole natural gas pipeline network was integrated into a new joint venture. Since then Norwegian natural gas transport is separated from production and selling. It became an independent and neutral part. The transportation facilities are no longer solely reserved by their owners. Any qualified shippers, included those who did not have any transportation facilities at all, can reserve the pipeline capacity on a fixed price at the present.

According to the tariff regulation of Ministry of Petroleum and Energy, the economic returns of natural gas transport facilities should be gained from the production field rather than the transportation system itself. However, as natural gas transportation is now separated from the production, those gas companies, who are planning to develop new pipelines, should consider such a decision more carefully.

In this paper, we analyze a two player game which describes the competition between two natural gas companies while they are developing new upstream natural gas pipelines. Tariffs are fixed by pipeline owners who are the two players in this game. Different consequences of different tariffs will be discussed.

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3http://www.npd.no(2007-3-16)
4http://www.gassco.no/sw3046.asp(2007-3-16)
The paper is organized as follow. In section 2, the two player simultaneous game is introduced. In section 3, Nash equilibria in the game based on different situations are found. Section 4 discusses the results of the game. In section 5, we give some suggestions for future work while section 6 concludes.

2 Literature review

Game theoretical and equilibrium models have already been introduced as an analytical tool for the European natural gas sector. The market structure of the sector is described by several equilibrium models. The GASTALE model (Boots et al., 2004), based on the work by Golombek et al. (1995, 1998), is constructed as a two-stage game. This model describes the European gas market in terms of upstream gas producers and downstream gas traders from a successive oligopoly perspective. A.Gabriel et al. (2005) and Gabriel and Smeers (2001) presents a competitive market equilibrium model involving most of the market participants in a natural gas market, such as producers, operators, marketers and consumers. These kinds of models focus on modeling the natural gas market structure, while our purpose is to plan the natural gas upstream infrastructure development. Nygreen et al. (1998) presents a large multiperiod mixed integer programming model which is a typical example of upstream project planning in petroleum industry. This MIP model decides when various fields and pipeline system should be started. But they do not take competition between companies into account. G.Klassen et al. (2004) analyzes the competition of two gas pipelines projects for a new gas market on a game theoretical model. They study the optimal commercialization time which is the time of finalizing the construction of the pipelines. However, the point of our paper is to decide how to build the pipeline system when there are several different ways to develop it.

3 Game of pipeline development

In this section, we construct a two-player, simultaneous-move game of pipeline development. Two natural gas companies plan to develop their new natural gas field in the same area. Instead of constructing new pipelines connecting to the market directly, they intend to build some new short-distance pipelines that connect the potential fields to an existing pipeline which leads to the market. Both of the companies have several alternatives of new pipelines. Figure 1 demonstrates this situation. In this figure, Pipeline 0 is the existing pipeline. In order to connect their production fields to the existing pipeline, players can choose to build pipelines among Pipeline 1 to 3 in Figure 1. The total profits gained from the production fields act as payoffs and the alternatives of new pipelines as well as tariff choices act as strategies. The game tries to decide which pipelines to be built and what tariffs to be chosen by the players. The main assumptions of the game are as follows:

1. The two natural gas companies are referred to as two players in this game,
Player 1 and Player 2 respectively.

2. The natural gas will be produced if and only if the production fields will be connected to the market by pipelines. Both of the players plan to connect their production fields to an existing pipeline leading to the market. It is assumed that this existing pipeline is owned by Player 2 and called Pipeline 0.

3. The tariff for using the pipelines is simply classified into two categories: a high tariff and a low tariff. It is naturally assumed that $T_{i}^{H} > T_{i}^{L}$. In addition, $T_{i}^{H} < I_{i}$ is assumed. Otherwise, it will be unreasonable to use the other player’s pipelines.

4. The tariff on Pipeline 0 is independent of Player 1’s other strategies. This means that the tariff $T_{0}^{p}$ is the same for Player 1 connecting Pipeline 0 by either Pipeline 1 or Pipeline 3.

5. The cost function for the pipeline investment is assumed as $I_{i}(l_{i})$, in which $l_{i}$ is the length of pipeline $i$. It is also assumed that $\frac{dI_{i}(l_{i})}{dl_{i}} > 0$. 

Figure 1: The game of pipeline development
6. The pipeline capacity is assumed as unlimited which means that pipelines, if built are always available. If both players build the same pipeline, they will only use their own ones, for the simple reason that their own pipelines is always enough.

7. Player 1 has several alternatives to develop his new pipelines. These following alternatives act as strategies:

(a) The first strategy is to build a direct pipeline connected to the existing pipeline. This is the Pipeline 1 in Figure 1.

(b) The second strategy is to build a pipeline connected to Player 2’s potential field, which is the Pipeline 2 in Figure 1.

(c) The last strategy is to build both Pipeline 2 and Pipeline 3. In this case, Player 2 can utilize Player 1’s newly built pipeline for transporting his production.

Player 1 also has other alternatives to develop pipelines, for example, Player 1 can build both Pipeline 1 and Pipeline 2. However, as unlimited capacity is assumed, one pipeline is enough for the transportation requirement. If Pipeline 1 is built, Player 1 will not have incentives to build more pipelines. Therefore, only the three listed alternatives are considered as Player 1’s strategies. Of course, if the capacity is limited, the situation will be different. Flexible will be important, and more alternatives can be a better choice in any case.

8. Player 2 can either build Pipeline 3 or avoid building any pipelines at all.

9. The payoff is the profits gained from the production fields. We simply define that the incomes are the revenue of the potential natural gas field and possible earning through pipeline tariffs, while the costs are the investments on constructing pipelines and the tariff which they should pay. It is assumed that the incomes are always much larger than the costs. This gives players incentives to develop the fields.

10. The parameters used in this game are stated below:

\[ I_i \] Construction investment for pipeline \( i \), \( i \in \{0, 1, 2, 3\} \);

\[ R_j \] Revenue of natural gas field \( j \), \( j \in \{1, 2\} \);

\[ T_i^q \] High or low tariff on pipeline \( i \), \( i \in \{0, 1, 2, 3\} \), \( q \in \{H, L\} \).

11. The game is assumed as a simultaneous-move game, which means that the players act at the same time and they do not know each other’s actions. It is natural to think that a player can easily observer his competitor’s action in real life, since those projects are huge. Hence this assumption may not be perfectly appropriate when the project is under constructing. However, during the decision-making stage, which is before any projects start, a simultaneous-move is still reasonable.
Figure 2: Payoff matrix of the game

12. Another assumption of the game is the complete information for each player. This means that players know all information about each others and themselves. But this can hardly happen in real business instances. Rational companies normally keep their key information secret. Moreover, the players may not know some information exactly themselves, such as the investments on pipelines. But in order to simplify the game, we still assume game of complete information.

According to these assumptions, the strategic form of this game is illustrated in Figure 2. The Player 1’s payoff is the lower line of each cell. The upper line is Player 2’s payoff.

We demonstrate how these payoffs are calculated by some examples. When Player 1 only build Pipeline 2, his field is connected to Player 2’s field rather than the existing pipeline. So if Player 2 chooses to avoid building any pipelines, neither of the production fields is connected to the existing pipeline. As a result, natural gas cannot be transported to the market, and there is no profit at all. Player 1’s payoff is $-T_2$, Player 2’s payoff is 0. However, if Player 2 constructs Pipeline 3, Player 2’s field is connected to the existing pipeline now. Meanwhile,
Player 1 can transport his natural gas through Pipeline 2, Pipeline 3 to Pipeline 0 and finally to the market. Since Player 2 owns Pipeline 3 and Pipeline 0, Player 1 has to pay the tariff and Player 2 can gain the tariff. So Player 1’s payoff is $R_1 - I_2 - T_0^q - T_3^q$ and Player 2’s payoff is $R_2 - I_3 + T_0^q + T_3^q$.

4 Nash Equilibria of the game

According to the terminology of game theory, when a Player 1’s strategy $s$ is the best reply to a Player 2’s strategy $t$ and $t$ is simultaneously a best reply to $s$, this strategy pair $(s,t)$ is a Nash Equilibrium (Binmore, 1992). Since this game is represented in a discrete way, we can directly find the Nash Equilibria from the strategic form by comparing each player’s payoff. It is observed that there are different Nash Equilibria under different circumstances in the given assumptions. Depending on different tariffs and constructing costs, the Nash Equilibria are different. We generalize them into four situations and describe them as below.

In the first situation, the game ends with a unique pure strategy Nash Equilibrium in which Player 1 builds Pipeline 1, Player 2 builds Pipeline 3 and Player 2 charges a high tariff on Pipeline 0. This is demonstrated in Figure 3. This situation happens when:

$$I_1 - I_2 < T_3^H < I_2 + I_3 - I_1$$ (1)

In the second situation, when inequality (2) is satisfied, the game also ends with a unique pure strategy Nash Equilibrium. This is represented in Figure 4. Player 1 builds Pipeline 2 instead of Pipeline 1. Player 2’s response is still the same, which is to build Pipeline 3 and charge a high tariff on both Pipeline 3 and 0.

$$T_3^H < I_1 - I_2 \text{ and } T_3^H < I_2 + I_3 - I_1$$ (2)

The third situation happens when $T_3^H$ falls into the range represented by inequality (3).

$$T_3^H > I_1 - I_2 \text{ and } T_3^H > I_2 + I_3 - I_1$$ (3)

This time, the game has two pure strategy Nash Equilibria and one mixed strategy Nash Equilibrium. The first pure strategy Nash Equilibrium is the same with the first situation’s, in which Player 1 builds Pipeline 1, Player 2 builds Pipeline 3 and Player 2 charge a high tariff on 0. The second pure strategy Nash Equilibrium here is that Player 1 builds both Pipeline 2 and Pipeline 3, Player 2 does not build any new pipelines at all, and both of the players charge a high tariff on the pipelines they owned. Furthermore, there is a mixed strategy Nash Equilibrium, which Player 1 builds Pipeline 1 with probability

$$\frac{I_3 - T_3^H}{R_2 - T_3^H}$$
and builds both Pipeline 2 and Pipeline 3 with probability

\[ 1 - \frac{I_3 - T_3^H}{R_2 - T_3^H} \]

Meanwhile, Player 2 chooses to avoid building any pipelines with probability

\[ \frac{I_2 + I_3 - I_1}{T_3^H} \]

and chooses to build Pipeline 3 with probability

\[ 1 - \frac{I_2 + I_3 - I_1}{T_3^H} \]

We prove that this values are in the interval (0,1) in Appendix which shows that the mixed strategy is feasible.

\[ I_1 - I_2 > T_3^H > I_2 + I_3 - I_1 \] (4)
Figure 4: Another possible developed pipelines

The last situation happens when inequality (4) is satisfied. The game also ends with two pure strategy Nash Equilibria and one mixed strategy Nash Equilibrium. One pure strategy Nash Equilibrium is the same with the second situation’s. The other pure strategy Nash Equilibrium is still that Player 1 builds both Pipeline 2 and Pipeline 3, Player 2 does not build any new pipelines at all, and both of the players charge a high tariff on the pipelines they owned. The mixed strategy Nash Equilibrium is that, Player 1 builds Pipeline 2 with probability

\[
\frac{I_3 - T_3^H}{R_2 + T_0^H}
\]

and builds both Pipeline 2 and Pipeline 3 with probability

\[
1 - \frac{I_3 - T_3^H}{R_2 + T_0^H}
\]

Meanwhile, Player 2 chooses to avoid building any pipelines with probability

\[
\frac{I_3 - T_3^H}{R_2 - T_0^H}
\]
and chooses to build Pipeline 3 with probability

\[ 1 - \frac{I_3 - T_3^H}{R_2 - T_6^H} \]

### 5 Discussions of the game

The four situations discussed in last section can be divided into two categories. In the first category, when \( T_3^H < I_2 + I_3 - I_1 \), the game ends with pure strategy Nash Equilibria. If the tariff for using Pipeline 3 is high enough, which means \( T_3^H > I_1 - I_2 \), Player 1 avoids using Pipeline 3 and builds Pipeline 1. Otherwise, Player 1 builds Pipeline 2 connected to Pipeline 3. In both situations, the Nash Equilibria give the lowest-cost strategies.

However, when \( T_3^H > I_2 + I_3 - I_1 \), the situations are more complicated. Mixed strategy Nash Equilibria are found. Here, if Player 1 builds both Pipeline 2 and Pipeline 3, and Player 2 uses Player 1’s pipeline, the payoffs of both Player 1 and 2 are the best. But this is a simultaneous move game, Player 1 does not know whether Player 2 will use his pipeline, meanwhile, Player 2 does not know whether Player 1 will build Pipeline 3. This leads to the mixed strategy Nash Equilibrium. But this is quite unnatural in real life. Because when Player 1 desire Player 2 using his pipeline, he should not keep his tariff decision secret from Player 2 and not play a simultaneous move. What Player 1 can do in this situation is to communicate his tariff decision with Player 2. Apparently, this will change the game into a sequential-move game, but both players can obtain a better result. Simultaneous moves are hence not necessary in this situation. Consequently, even if the game can end with a mixed Nash Equilibrium, it will seldom happen.

It is also found that only the high tariff is relevant to different Nash Equilibria among the two categories of tariffs. The variation of low tariffs does not affect the final results. Any low tariff strategies are weakly dominated by their high tariff strategy counterparts. So pipeline owners will choose a tariff as high as possible in a certain range. However, this can be changed in a multi-period game. When the tariff is negotiated year by year, which is more realistic, the players have to be responsible for their previous behavior. This is not represented by our one-shot game. So our intuition tells us that different results may be obtained in a multi-period game.

In this game, some assumptions are different from the real situation. As we mentioned before, the current Norwegian upstream natural gas infrastructures are integrated into one company, and the tariff is fixed by the state-owned company Gassco. Hence, the tariff is not set up by pipeline owners. Every player should know the tariff even before the pipeline is constructed. The tariff should be common knowledge in the game. We can simply assume that the tariff satisfies one of the inequalities (1)-(4) and find what will happen.\(^6\)

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\(^6\)This is not completely right. Because Gassco will be a new player in the game.
Since the authorities intend to ensure that the economic returns of pipelines are earned from production fields instead of the transportation system itself, the current tariff should be much less than investments of pipelines. We can simply assume that the current tariff satisfies the inequality (2), for the tariff here is the smallest one. The result is represented in Figure 4, where Player 1 builds Pipeline 2 and Player 2 builds pipeline 3. In this situation, Player 1 builds his pipeline in a minimum length, and transports his natural gas mostly by Player 2’s pipelines. It is reasonable because the tariff is cheap and the game assumes that the pipelines are always available. This means that Player 1 can rely on Player 2’s pipelines. This situation is very similar with the current open access and fixed tariff policy in Norway. One of the Gassco’s visions is to provide reliable natural gas transportation. But when the natural gas transportation is reliable, the players may lose their incentives to build larger pipelines and minimize the pipelines’ size, just like what Player 1 does here.

Tariffs play an important role in the pipeline development. It is one of the most crucial incentives for developing pipelines, and it represents the power of pipeline owners. According to the results of the game, different tariffs lead to varied ways of pipeline development. If pipeline owners can set tariffs on their own pipelines, they would have many options to develop new pipelines. However, the fixed tariff policy in the Gassco system limits the alternatives of pipeline development. This tariff policy is aimed for a current reliable transportation system, not for the future development. Apparently, it is not an optimal solution for the pipeline development. The Gassco system not only takes parts of pipeline owners’ power, but also limits the options of pipeline development. This leads the pipeline owners to lose their incentives to develop new pipelines. Between 1993 and 2001, new natural gas pipelines were built every year on the Norwegian Continental Shelf. But after 2002, only one pipeline were built.

When there is no incentive to develop more new pipelines, Gassco may face potential problems for the current transportation system. One of the Gassco’s visions is to ensure an optimum utilization of its infrastructure. After two capacity booking rounds in 2006, very little spare capacity is available for sale to the primary market during the contract years up to 2015 and 2016. This indicates that the utilization of current transportation system will be quite high. On one side, Gassco fulfills one of its visions. But on the other side, an extremely high utilization is also a risk for the transportation system. The Norwegian natural gas export will keep increasing in the next decade (Figure 5). So it can be a problem how to ensure this increasing export under the current high utilization system. In many cases, it may be appropriate to build the pipelines somewhat larger than initial needs, so that any new gas discoveries can be transported through the existing pipelines system. But as we discussed, companies may lose their incentives to do so under the current natural gas transportation system in Norway. Hence, when Gassco is trying to provide a safe and reliable natural gas transportation system, and to raise utilization of the system, it should also be very careful about the consequence in the development

\(^7\) See “Gassco Annual Report 2006”.
of new pipelines.

6 Future works

There are some crude assumptions in this game. We can relax these assumptions to make them more reasonable and realistic.

The first crude assumption is the unlimited pipeline capacity. The limited capacity is one of the most important features in a natural gas pipeline system. If the game assumes that the pipeline capacity is limited, more conflicts will occur. For example, when Player 1 only build Pipeline 2, he should consider the capacity of Pipeline 3. The capacity of Pipeline 3 may hence not be high enough for the natural gas from both production fields.

The choice of tariff is another crude assumption in our model. It is represented as a total expense. However, it is better to denote the tariff as a unit cost which is used in real life. Then the total expense can be represented as multiplying unit costs by transportation quantity (usually in standard cubic meter). Of course, the transportation quantity cannot exceed the capacity of pipelines.

We built a two-player game in this paper. But there could be more players. Both more than 2 natural gas companies as well as the “market regulator” Gassco could be considered as players in an extended game model. This new company(Gassco) plays an important role in the Norwegian upstream natural gas pipeline system. When we try to model the current situation, it is necessary
to consider Gassco’s power.

7 Conclusions

This paper describes a two-player simultaneous game, in which two natural gas companies intend to develop new pipelines in order to make their new gas production fields profitable. It is found that different Nash Equilibria occur when tariffs vary in different spaces. Therefore, tariffs can definitely influence how new pipelines will be developed. Moreover, when natural gas companies can rely on others’ transportation facilities, they will minimize their new pipelines’ size. This situation is happening similarly in Norwegian upstream gas infrastructures. When Gassco is trying to provide a safe and reliable transportation system, it can also reduce the size of new infrastructure. Since the Norwegian natural gas export keeps increasing recent years, the transportation system have to secure this increasing supply. The low incentives of developing larger pipelines than initial needed should be payed attention to.

Appendix

This appendix finds the mixed strategy Nash Equilibrium when the tariff satisfies the inequality (3) and prove that it is feasible.

In order to find the mixed strategy Nash Equilibrium, dominated strategies are deleted. The reduced strategic form is gotten below.

<table>
<thead>
<tr>
<th></th>
<th>Not Build</th>
<th>Pipeline 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HT on 3, HT on 0</td>
</tr>
<tr>
<td>Pipeline 1</td>
<td>$T_0^H$</td>
<td>$R_2 - I_3 + T_0^H$</td>
</tr>
<tr>
<td></td>
<td>$R_1 - I_1 - T_0^H$</td>
<td>$R_1 - I_1 - T_0^H$</td>
</tr>
<tr>
<td>Pipeline 2 and 3</td>
<td>$R_2 + T_0^H - T_3^H$</td>
<td>$R_2 - I_3 + T_0^H$</td>
</tr>
<tr>
<td></td>
<td>$R_1 - I_2 - I_3 - T_0^H + T_3^H$</td>
<td>$R_1 - I_2 - I_3 - T_0^H$</td>
</tr>
</tbody>
</table>

Assume that Player 1 chooses to build Pipeline 1 with probability $p$, build Pipeline 2 and 3 with probability $1-p$, and that Player 2 chooses to avoid building any pipelines with probability $q$, build Pipeline 3 with probability $1-q$. If $p,q$ is a mixed strategy Nash Equilibrium, the expected payoff to every strategy is the same. For Player 1’s strategies, we can obtain following equation:

$$q \ast (R_1 - I_1 - T_0^H) + (1 - q) \ast (R_1 - I_1 - T_0^H) = q \ast (R_1 - I_2 - I_3 - T_0^H + T_3^H)$$

$$+ (1 - q) \ast (R_1 - I_2 - I_3 - T_0^H)$$

For Player 2’s strategies, we obtain:

$$p \ast T_0^H + (1 - p) \ast (R_2 + T_0^H - T_3^H) = p \ast (R_2 - I_3 + T_0^H) + (1 - p)(R_2 - I_3 + T_0^H)$$

We calculate that the only possible mixed strategy Nash Equilibrium is
This mixed strategy Nash Equilibrium occurs when tariff satisfies inequality (4), in which \( I_2 + I_3 - I_1 < T_3^H \). Therefore,

\[
0 < \frac{I_2 + I_3 - I_1}{T_3^H} < 1
\]

The game assumes that the field value is much larger than construction costs of pipelines that means \( R_2 > I_3 \). According to inequality (4), \( T_3^H < I_3 \), we can also obtain:

\[
0 < \frac{I_3 - T_3^H}{R_2 - T_3^H} < 1
\]

Since \( p \) and \( q \) are in the interval \((0,1)\), this mixed strategy is feasible.

The same way can be used to find the mixed strategy Nash Equilibrium when inequality (4) is satisfied.

References


