Regulatory Reform and Network Expansion:
Case of the Japanese Natural Gas Industry

Masahiro ISHII (Sophia University)
Satoru HASHIMOTO (Teikyo University)
Koichiro TEZUKA (Nihon University)

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1 Introduction

1.1 Background

- Regarding the network infrastructure industries such as gas, electricity, railway, road etc.,
  
  How to invest, construct and expand the network

  is one of the important issues.

- As for the natural gas industry, in US and EU such as the UK, France, Germany, and Italy,
  
  After the construction of the pipeline networks, deregulation schemes were enforced.
cont.

- In contrast, some countries such as East European countries and Japan have not completed natural gas pipeline networks throughout the countries.

Now, these countries have to execute deregulation. At the same time, these countries have to continue to extend the pipeline network infrastructure.
• With respect to Japanese gas industry,

At the end of 2012, the trunk pipeline (high pressure pipeline) was approximately 3000 km in length, which is quite smaller than that in the US and EU.

• For example,

* The distance between Tokyo and Osaka is about 400 km.

No trunk pipeline exists between them.

* The distance between Berlin and Paris is about 880 km.

There exits a trunk pipeline connecting these cities.
Despite this situation, Japanese government decided to enforce the unbundling regulation that spins off an incumbent into a pipeline network company and a supplier, and it will be introduced in 2017.

However, the government has not considered the importance of pipeline network construction.
1.2 Research Question

- We examine how a network company commits to construct the pipeline network under the regulatory reform.

In other words, we see the effects of the policies, which are related with vertical structure (integration/separation), on the pipeline network expansions.

- To address this problem, we construct a structural model to analyze a relation between vertical structure and network expansion, and obtain some results from the model.
2 Model

- Natural gas is supplied to consumers through a network, which is owned by only one firm.

- Two stage game with 1st stage and 2nd stage
  
  **1st stage**
  A network size is determined.

  **2nd stage**
  A natural gas price is settled between suppliers and consumers.
### Outlook

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Distribution of the consumers (consumption)

* $N$ and $\lambda$ are positive constants.

\[ f(t) = N\lambda e^{-\lambda t} \quad \text{for } t > 0. \quad (1) \]

* $f$ expresses a distribution of the consumers (consumption) on $(0,\infty)$.

* When the natural gas price is equal to 0,
  \[ \Rightarrow \text{The density of consumption at a point } t \text{ is } f(t), \]
  \[ \Rightarrow \text{The network can be extended over } (0,\infty) \]
  \[ \Rightarrow \text{The total consumption is } N. \]

* The consumption is a decreasing function with respect to the distance from the origin.

* The parameter $\lambda$ determines the decreasing degree.
cont.

- Inverse demand function
  * $a$ is a positive constant.

\[ g(t, x) = a - \frac{ae^{\lambda t}}{N\lambda} x \quad \text{for } t > 0, \ 0 \leq x \leq N\lambda e^{-\lambda t}. \]

(2)

where the variable $x$ denotes demand.

* $g(t, x)$ is an inverse demand function at point $t$.

* The maximum willingness to pay is assumed to be constant, i.e. $a$, over the interval $(0, \infty)$. 
cont.

- Initial network size
  - A non-negative constant $u_0$ is an initial network size, that is, $(0, u_0]$ is the network at the beginning of the 1st stage.
  - When the network is not extended at all at the 1st stage,
    $\Rightarrow$ Natural gas is supplied to only the consumers in $(0, u_0]$ at the 2nd stage.
Network expansion cost $K_j (j = 1, 2)$

* We assume that a twice continuously differentiable function $K_j : [0, \infty) \rightarrow [0, \infty)$ satisfies

\[
K_j(0) = 0, \quad \frac{dK_j}{du}(u) > 0, \quad \frac{d^2K_j}{du^2}(u) \geq 0.
\]

Hereafter, $K'_j(u) = \frac{dK_j}{du}(u)$.

* When the network is extended from $u_0$ to $u_0 + u$, $K_j(u)$ is required for the network increment $u$.

* $K_j$ depends on:

  ◇ Direct cost for the network expansion
    (construction materials, labor and so on)
  ◇ Financing cost
Marginal cost

* The marginal cost to supply natural gas (unit operating cost) at the 2nd stage is denoted by a positive constant $c$.

* The marginal cost is assumed to depend neither the network size nor the supply, which is constant.
Comparison from the view of gas price and network size

(i) Vertical integration (monopoly)
   * Firm $B_1$ extends the network, monopolistically supply the gas to the consumers.

(ii) Vertical separation
    (one transmission operator and competitive suppliers)
    * Firm $B_{21}$ is the transmission network operator, and can extend the network.
    * Firm $B_{22}$ and firm $B_{23}$ have to pay firm $B_{21}$ access charges to supply gas.
# 3 Gas Price and Network Size

## 3.1 Vertical integration (monopoly)

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Firm $B_1$ has the network and decides the size.

Only firm $B_1$ supplies gas through the network.

The network expansion cost is $K_1$.

Firm $B_1$ selects a gas price and a size of the network to maximize its profit.
Total Demand over the Network

- $u \geq 0$

- When firm $B_1$ selects a gas price $y \in [c, a]$, the demand at a point $t \in (0, u_0 + u]$ is

$$x = \frac{(a - y)N\lambda e^{-\lambda t}}{a}.$$ 

Then, the total demand over the network $(0, u_0 + u]$ is

$$\int_{0}^{u_0+u} \frac{(a - y)N\lambda e^{-\lambda t}}{a} \, dt = \frac{(a - y)N}{a} \left(1 - e^{-\lambda(u_0+u)}\right)$$

(3)
Profit of Firm $B_1$

- Let the gas price be $y \in [c, a]$.

  Since the total demand is (3), and the marginal cost (unit operating cost) is $c$,

  the profit of firm $B_1$ is given by

  $h_1(u, y) = (y - c) \frac{(a - y)N}{a} \left( 1 - e^{-(u_0+u)} \right) - K_1(u)$. (4)

- Firm $B_1$ chooses a $(u, y)$ which maximizes $h_1(u, y)$. 
Theorem 3.1
For the monopoly firm B₁, the pair of network size and gas price \((u, y)\) maximizing the profit \(h_1(u, y)\) is

\[
(u, y) = \begin{cases} 
\left(0, \frac{a + c}{2}\right) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} < K'_1(0) \\
\left(u_1^*, \frac{a + c}{2}\right) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} \geq K'_1(0)
\end{cases}
\]

(5)

where \(u_1^*\) is a unique solution of the following equation:

\[
\frac{\partial h_1}{\partial u} \left( u, \frac{a + c}{2} \right) = 0.
\]

(6)
3.2 Vertical Separation

- The network is operated by firm B$_{21}$ which is independent of gas suppliers.

- Firm B$_{22}$ and B$_{23}$ are gas suppliers.

- Every supplier has to pay an access charge to firm B$_{21}$ for each unit of gas it delivers to the consumers.

- If $v \in [0, a - c]$ is the access charge, firm B$_{2k}$ pays $v \times$ the supply by firm B$_{2k}$

  to supply natural gas through the network.
### 3.2.1 Basic Model

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cont.

- At the 2nd stage, Firm B_{22} and B_{23} compete with price given
  * the network \((0, u_0 + u]\),
  * the access charge \(v\).

- The Nash equilibrium of this game is
  \[(c + v, c + v).\]  \hspace{1cm} (7)

- The total supply to the network \((0, u_0 + u]\) is
  \[
  \frac{(a - c - v)N}{a} \left(1 - e^{-\lambda(u_0+u)}\right).
  \]  \hspace{1cm} (8)
At the 1st stage, firm B_{21} is assumed to have perfect foresight. Then, firm B_{21} knows the results of the 2nd stage, that is, (7) and (8).

Firm B_{21}
* extends the network size by \( u \),
* sets the access charge \( v \)
to maximize the profit.

The network expansion cost is \( K_2 \).

The profit of firm B_{21} is

\[
h_{21}(u, v) = v \frac{(a - c - v)N}{a} \left( 1 - e^{-\lambda(u_0+u)} \right) - K_2(u) \tag{9}
\]
Theorem 3.2
For the network operator firm $B_{21}$, the pair of network size and access charge $(u, v)$ maximizing the profit $h_{21}(u, v)$ is

$$
(u, v) = \begin{cases} 
(0, \frac{a - c}{2}) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} < K'_2(0) \\
(u^*_2, \frac{a - c}{2}) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} \geq K'_2(0)
\end{cases},
$$

(10)

where $u^*_2$ is a unique solution of the following equation:

$$
\frac{\partial h_{21}}{\partial u} \left( u, \frac{a - c}{2} \right) = 0.
$$

(11)
Based on Theorem 3.1 and Theorem 3.2, we obtain the following results:

For each one of two cases,

(a) vertical integration,

(b) vertical separation,

the equilibrium gas price is \( \frac{a + c}{2} \).

If \( K'_1 = K'_2 \) holds, the extended network sizes are equal.
cont.

- If \( K_1' < K_2' \)

\[ \Rightarrow \] the network size under (b) is not greater than that under (a).

- For example,
  * Firm B₁ is split into
    the transmission network of firm B₁ is carved out and starts operating as a separated firm B₂₁,
  gas supply sector of firm B₁ changes to firm B₂₂.
  * After that, B₂₃ entered this market.

\[ \Rightarrow \] the capital cost of firm B₂₁ increases.

\[ \Rightarrow K_1' < K_2'. \]
### 3.2.2 Access Charge Regulation

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The regulator sets the access charge at a fixed level \( v_0 \in [0, a - c] \).

Apparently, the Nash equilibrium of the 2nd stage game is

\[
(y_2, y_3) = (c + v_0, c + v_0).
\]

(12)

Then,

\[
\frac{\partial h_{2,1}}{\partial u}(u, v_0) = \frac{N \lambda e^{-\lambda (u_0 + u)}}{a} \left\{ - \left( v_0 - \frac{a - c}{2} \right)^2 + \frac{(a - c)^2}{4} \right\} - K_2'(u).
\]

(13)
Corollary 3.2.1

Under the condition that the access charge is given by $v_0$, the network expansion $u$ maximizing the profit $h_{21}(u, v_0)$ is

$$u = \begin{cases} 
0 & \text{for } \frac{N\lambda e^{-\lambda u_0}}{a} \left\{ - \left( v_0 - \frac{a - c}{2} \right)^2 + \frac{(a - c)^2}{4} \right\} < K_2'(0) \\
\bar{u}_2 & \text{for } \frac{N\lambda e^{-\lambda u_0}}{a} \left\{ - \left( v_0 - \frac{a - c}{2} \right)^2 + \frac{(a - c)^2}{4} \right\} \geq K_2'(0)
\end{cases},$$

(14)

where $\bar{u}_2$ is the unique value which satisfies the following equation

$$\frac{\partial h_{21}}{\partial u}(u, v_0) = 0.$$
cont.

• It is clear that

\[ \bar{u}_2 < u_2^* (\leq u_1^*) \text{ for } v_0 \neq \frac{a - c}{2}. \]

• If the regulator does not choose the optimal access charge, which is optimal for the network operator, the network is smaller under the access charge regulation.
3.2.3 Two-part Tariff

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Both suppliers put up good-faith deposit to the network operator.

Let a function $L : [0, \infty) \to [0, \infty)$ satisfy

$$L(0) = 0 \text{ and } \frac{dL}{du}(u) > 0.$$ 

Hereafter, $L'(u) = \frac{dL}{du}(u)$.

A positive constant $r$ denotes the capital cost of each firm.
cont.

- Economic interpretation of $L$
  
  * For each $k = 2, 3$, firm $B_{2k}$ is required to deposit $\frac{L(u)}{2}$ into firm $B_{21}$, before it supplies gas through the network.
  
  * After the extension, firm $B_{21}$ will refund the money amount back to each supplier.
  
  * Then,
    
    * Firm $B_{21}$ has a chance to invest an amount of money $L(u)$, that is, $rL(u)$.
    
    * Each one of firm $B_{22}$ and firm $B_{23}$ incurs financing cost of $\frac{rL(u)}{2}$. 
cont.

- $L(u)$ is assumed to depend on an increment of the network,
  
  but not to depend on gas supplied by firm B_{22} and firm B_{23}.

- To access the network, each supplier pays a kind of two-part tariff, where $\frac{rL(u)}{2}$ is the fixed fee and $v$ is the variable fee.
cont.

- For firm $B_{22}$ and $B_{23}$, the profit function is

  \[ h_{22}(u, v) + \frac{rL(u)}{2} \]

  \[ \Rightarrow \quad \text{The Nash equilibrium at the 2nd stage game is given by (7) that is the same in the basic model.} \]

- The profit function of firm $B_{21}$ is

  \[ h_{21}(u, v) + rL(u) \quad (15) \]
Corollary 3.2.2
Suppose that the second derivative of $L$ is not positive. The profit of the transmission operating firm $B_{21}$ is maximized at the following point:

$$
(u, v) = \begin{cases} 
(0, \frac{a - c}{2}) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} < K_2'(0) - rL'(0) \\
(u_3^*, \frac{a - c}{2}) & \text{for } \frac{(a - c)^2 N \lambda e^{-\lambda u_0}}{4a} \geq K_2'(0) - rL'(0)
\end{cases}
$$

(16)

where $u_3^*$ is the unique value which satisfies the following equation

$$
\frac{\partial h_{21}}{\partial u} \left( u, \frac{a - c}{2} \right) + rL'(u) = 0.
$$
Corollary 3.2.3

(i) If $K'_1 < K'_2$,

$$L(u) = \frac{K_2(u) - K_1(u)}{r}$$

leads to the same network size achieved in the monopoly case (5).

(ii) In the access charge regulation, that is, a fixed access charge $v_0$ is adopted,

$$L(u) = \frac{Ne^{-\lambda u}}{ar} \left( v_0 - \frac{a - c}{2} \right)^2 (1 - e^{-\lambda u})$$

gives us the same network size achieved in the basic model (10).
cont.

- $L$ in Corollary 3.2.3 (i):
  
  Since an increase in the capital cost, which is caused by the vertical separation, is compensated by the gas suppliers, the increment of the network $u_1^*$ is accomplished.

- $L$ in Corollary 3.2.3 (ii):
  
  Even if the access charge is settled at $v_0 \neq \frac{a - c}{2}$, the total good-faith deposit $L$ yields the increment of the network $u_2^*$. 
cont.

- Supplement

  * If \( L \) satisfies
    \[
    \frac{d}{du} (K_2(u) - rL(u)) > 0 \text{ and } \frac{d^2}{du^2} (K_2(u) - rL(u)) \geq 0,
    \]
    we obtain the same result in Corollary 3.2.2.

  * The design of \( L \) can be applied to implement the desired extension of transmission network.
4 Conclusion and Future Research

Conclusion

Implications of our model:

- Vertical separation decreases incentive to invest in the network extension.
- Access charge regulation also decreases the investment incentive.
- In order to spread the transmission network after the vertical separation, regulations including network access fees should be designed to increase the investment incentive.
Future Research

- Social welfare
- To compare legal vertical separation with accounting separation
- Uncertainty of natural gas price
Thank you for your attention!