Partial Authority Allocation of Regional Water Supply System in Indonesia and Economic Efficiency

Masamitsu ONISHI[1], Mangapul L. NABABAN[2] and Kiyoshi KOBAYASHI[3]

[1]Assistant Professor, Graduate School of Engineering, Kyoto University
(C1-333, Kyoto University Katsura Campus, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:onishi.masatmisu.7e@kyoto-u.ac.jp
[2]PhD Student, Graduate School of Engineering, Kyoto University
(C1-337, Kyoto University Katsura Campus, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail: nababan.lammiahan.33a@st.kyoto-u.ac.jp
[3]Professor, Graduate School of Management, Kyoto University
(Yoshida Honmachi, Sakyo-ku, Kyoto 606-8501Japan)
E-mail: kobayashi.kiyoshi.6n@kyoto-u.ac.jp

Our study is motivated by a problem that we observed in Bandung region in Indonesia where the operation of water supply system has been influenced by the decentralization policy in 2001. Decentralization has allocated the authority over the operation of water supply system which covers multiple local governments' territories to one of them as observed in Bandung region. This paper aims to analyzing the economic consequence of 'partial authority allocation' caused by decentralization in Indonesia. As a result, we identified the partial authority allocation among local governments is a substantial factor of underinvestment of urban area. In addition, several feasible policies are proposed based on the implication of our analysis.

Key Words : *water supply system, decentralization policy,*

1. INTRODUCTION

Without water, no one can survive. Water is definitely essential for life. But water is not ubiquitous. Human being is seeking security of water availability in any age. Stable availability of clean water is still a great challenge in developing countries. The millennium development goals of UNDP[1)] include halving the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. A number of reports have pointed out the inadequacy of water supply in urban areas, where poor households seldom have networked water supply access[2)-6)].

Difficulties concerning water availability come not only from nature and technology such as climate and geography but also from socio-economic reason such as financial availability, national administration system and so on. Moreover, those factors are usually interrelated and forming a complex system.

In fact, difficulties concerning water supply have attracted an academic attention from a variety of disciplines from engineering to social science including sociology, economics and political science. This implies that problems concerning water are complex and requires a comprehensive consideration about the local uniqueness in terms of geography and socio-economic environment.

Our study is motivated by a problem that we observed in Bandung region in Indonesia where the operation of water supply system has been influenced by the decentralization policy in 2001. Decentralization promoted by the government of Indonesia has vested authority to determine substantial issues related to water supply system to local governments.

A critical fact we observe there is that geographical territory of a local government's jurisdiction does not necessarily coincide with that of local water supply system. Theoretically, In other words, a closed system of water supply would cover multiple local governments' territories. According to the famous principle of fiscal principle developed by Olson[7)], we have to have one layer of the government for each public good although it does not consider the individuals' mobility. Coverage of multiple local governments' jurisdiction means that decisions concerning the operation of water supply system attract their interests that may not be consistent with each other. A decision making process of water supply system should build in a coordination system that compromise interests of stakeholders.

Unfortunately, actual implementation of decentralization policy in Indonesia has not necessarily regarded the need of coordinating local governments' conflicting interests. As Nababan *et al.*[8] observed, there is a case that the authority of operating water supply system which covers multiple local governments' territories is monopolized by one local government among them as is observed in Bandung region. The interest of our study is a problematic consequence of this 'partial authority allocation' from the economic point of view. The study aims at developing a descriptive model to explain the mechanism how the economic inefficiency arises from the partial authority allocation. In addition, we discuss feasible policies to overcome the identified problem.

The paper is organized as follows. Section 2 describes the current institutional environment after decentralization in Bandung region in Indonesia, which motivates us to conduct this study. In section 3 and 4, a descriptive model is developed to analyze the economic efficiency under the current institutional environment. Section 3 analyzes the case of symmetric local governments, whereas section 4 analyzes the case of asymmetric local governments. As a result, we point out that the asymmetricity regarding the availability of water is a source of potential conflict of interest and leads to the economic inefficiency. In section 5, several feasible policies are proposed based on the implication of our analysis. Section 6 concludes the paper.

2. BASIC IDEA OF THE STUDY

(1) Institutional system of water supply system after decentralization in Bandung Region

Our study is motivated by the problem concerning with institutional consequence of decentralization in Indonesia in 2001 observed in Bandung region. In Indonesia, utility of water supply is provided by public enterprises called PDAM. PDAM is responsible for seeking and developing water source and facilities for water treatment and transmission. PDAMs are government-subsidiary entities and hence controlled by local governments after the decentralization in 2001. Territory where a PDAM covers is not necessarily a single local government. Rather it is common that a PDAM covers multiple local governments' territories due to the geographical reason.

This is the case in Bandung region. PDAM Tirta Raharja supplies water to Bandung Regency, West Bandung Regency and Cimahi City. Any decision-makings of PDAM Tirta Raharja should attract the concerns of its coverage municipalities. However, the ownership of PDAM Tirta Raharja has been allocated only to Bandung Regency since decentralization was promoted, and West Bandung Regency and Cimahi city are excluded from the formal decision making process of PDAM Tirta Raharja. Cimahi City is originally recognized as a military area where a number of military facilities locate. However, Cimahi City has recently experienced population growth which leads to increasing demand of water for drinking and household use as well as commercial use. On the other hand, Bandung Regency which has 100% ownership of PDAM Tirta Raharja is rather sparsely populated and covers mountainous area. This implies that people in Bandung Regency is easier to acquire alternative water source other than PDAM compared to people in Cimahi City.

(2) Problem identification

The paper is partly motivated by a frustrated feeling of Cimahi City government. Due to the increase of population, they wish to expand networked water supply system. However, the Cimahi City government does not have a control over the PDAM Tirta Raharja. Intuitively, the investment for pipeline network in Cimahi City is inadequate. Our study aims at exploring a mechanism how under investment for the pipeline network in populated area under the current governance system of PDAM Tirta Raharja from the theoretical point of view.

We focus upon the asymmetricity in geographical condition between Cimahi City and Bandung Regency, authority of PDAM Tirta Raharja. Cimahi City is steadily growing, but alternative water resources are not rich compared to the surrounding mountainous areas including Bandung Regency. It is shown that the difference in richness of alternative water sources could be a critical factor that induces the underinvestment in Cimahi City. In addition, PDAM Tirta Raharja gains positive surplus from Cimahi City which is transferred for the investment into expanding the network in Bandung Regency, when the government of Bandung Regency behaves rationally.

Another source of the problem of partial authority allocation is rather a technical attribute. Pipeline is essential for connecting to water supply network. Without pipeline, people cannot use the networked water. This implies that the investment for pipeline is economically interpreted as purchasing a financial 'option' to use the networked water. The value of option is apparently depending on the availability of alternative water sources. A household with less alternative water sources may value option, i.e. pipeline higher compared to a household with more alternative sources.

In summary, the purpose of the study is to prove theoretically that partial authority allocation could be problematic if there exists the difference in richness of alternative water sources and pipeline as an option,

3. MODEL

(1) Settings

The economy consists of two regions; Region 1 and Region 2. The population of two regions is symmetric and standardized as 1. Individuals of the economy are assumed to be immobile. PDAM is a corporation established to supply water. It is assumed that only the Region 1 government has authority to determine the price of water and investment for pipelines in two regions. This assumption reflects the partial ownership allocation of water supply system in Indonesia. The price of PDAM water cannot be discriminated between Region 1 and Region 2.

(2) Technology

Costs of PDAM water supply system consists of two components: cost associated with the volume of supplied water (e.g. water treatment cost) and cost associated with the initial investment which determines the capacity of water supply (e.g. pipeline construction). Fixed cost components are not considered. The total cost of PDAM water supply system is formulated as

$$C(x_1, x_2, n_1, n_2) = c(x_1 + x_2) + c_f(n_1 + n_2) \tag{1}$$

x_i denotes the aggregate volume of supplied water for Region i and n_i denotes the number of households that have access to the pipeline network of PDAM. Hence, n_i is the maximum volume of water supply (i.e. capacity of water supply system) in Region i, i.e. $x_i \le n_i$. n_i is called hereinafter 'network capacity'. A fixed cost of the investment for facilities such as water treatment plants that benefits both of Region 1 and Region 2 is not considered.

For the simplicity of following analysis,

$$c = \frac{1}{1+k} \tag{2}$$

$$c_f = \frac{k}{1+k} \tag{3}$$

is assumed.

(3) Demand

Households consume one unit of water. Households do not necessary use water supplied by PDAM exclusively. It is very common for the Indonesian to use private wells or community-based water supply system, which is hereinafter called as alternative water sources. Hence, households choose PDAM or the alternative water sources in consuming one unit of water. ρ is the cost of using alternative water sources which is distributed according to the cumulative distribution function $F_i(\rho) = a_i\rho$ in Region i, where $\rho \in [0, 1/a_i]$.

Given the price of PDAM water p, a household whose cost of using alternative water sources is ρ chooses PDAM if $p \le \rho$ and alternative water sources if $p > \rho$. The aggregate demand function of PDAM water without the capacity constraint, which is called as the potential aggregate demand hereinafter, is calculated as

$$\bar{x}_i(p) = 1 - F_i(p) = 1 - a_i p. \tag{4}$$

The inverse aggregate demand function is

$$\bar{P}_i(x_i) = \frac{1 - x_i}{a_i} \tag{5}$$

The symbol "$^-$" denotes the demand is 'potential' and unconstrained by the capacity. When the capacity constraint is considered, a household may not obtain PDAM water even the price of PDAM water is cheaper than the cost of alternative water sources. If the potential aggregate demand exceeds the capacity, i.e. $\bar{x}_i(p) > n_i$, the capacity constraint is effective. $\bar{x}_i(p) > n_i$ implies $\bar{P}_i(n_i) > p$. In this case, it is assumed that households with $\rho \ge \bar{P}_i(n_i) = (1 - n_i)/a_i$ consume one unit of PDAM water. And households with $\rho < \bar{P}_i(n_i)$ use the alternative water sources. Hence, the 'real' aggregate demand function with the capacity constraint given p is

$$x_i(p, n_i) = \begin{cases} 1 - a_i p & \text{if } 1 - a_i p < n_i \\ n_i & \text{if } 1 - a_i p \ge n_i \end{cases}. \tag{6}$$

$\bar{P}_i(n_i)$ is a threshold to determine whether the capacity is fully utilized or not depending on the setting of p. In other words, in order to fully utilize the capacity n_i, the price must be set less than $\bar{P}_i(n_i)$.

In addition,

$$\bar{x}_i(c + c_f) = 1 - a_i(c + c_f) \gg 0 \Leftrightarrow a_i \gg 1 \text{ for } i = 1, 2 \tag{7}$$

is assumed. This assumption guarantees that when the water is supplied at the price of minimum marginal cost, sufficiently enough aggregate demand exists.

(4) Cost for water acquisition

The total cost of water acquisition in Region i is defined as

$$TC_i = p x_i(p, n_i) + \int_0^{\max[p, \bar{P}_i(n_i)]} \rho dF_i(\rho). \tag{8}$$

The first term of LHS denotes the cost spent by households that use PDAM water and the second term denotes the cost for usage of alternative water sources.

PDAM gains revenue from households using PDAM water for the in compensation for being responsible for water supply and network investment. The revenue of PDAM coming from Region i is represented by $R_i = px_i(p, n_i)$ as PDAM cannot differentiate the price in Region 1 and Region 2. The cost of supplying PDAM water for Region i is

$$C_i = cx_i(p, n_i) + c_f n_i. \tag{9}$$

For the analytical convenience, define

$$\theta_i = \frac{x_i(p, n_i)}{n_i} \tag{10}$$

that denotes the ratio of usage ratio against the capacity of pipeline. θ_i must be $0 \le \theta_i \le 1$. The cost of PDAM water supply C_i is written as

$$C_i = m_i n_i \text{ and} \tag{11}$$

$$m_i = \frac{\sigma_i + k}{1 + k}. \tag{12}$$

where $\sigma_i = 1/\theta_i (\ge 1)$. m_i is regarded as the apparent marginal cost of water supply in Region i. Profit of PDAM is written as

$$\begin{aligned} \pi_i &= R_i - C_i \\ &= (p - m_i) n_i \end{aligned} \tag{13}$$

When the capacity of pipeline is fully utilized, the marginal cost is 1. However, if the capacity of pipeline is not fully utilized, the marginal cost is getting larger than 1 as θ_i decreases.

The profit of PDAM is the sum of the profit from Region 1 and Region 2. That is

$$\pi = \pi_1 + \pi_2 \tag{14}$$

The followings are some important properties on the total cost of water acquisition which are frequently used in the following analysis.

$$\frac{\partial TC_i}{\partial p} > 0 \tag{15}$$

$$\frac{\partial TC_i}{\partial n_i} \begin{cases} < 0 & \text{if } p < \bar{P}_i(n_i) \\ = 0 & \text{if } p \ge \bar{P}_i(n_i) \end{cases} \tag{16}$$

(15) means that the total cost of water acquisition is always strictly increasing in the price of PDAM water. (16) means the expanding the supplying capacity contributes to decreasing the total cost when the capacity is constrained, but not when it not the case.

(5) The case of impartial authority allocation

When the authority over the PDAM is impartially allocated, it concerns the welfare of Region 1 as well as Region 2, the price of PDAM water and the level of network capacity must be set to minimize the total cost of water acquisition in Region 1 and Region 2, which is formulated as follows.

$$\min_{p, n_1, n_2} TC_1 + TC_2 \tag{17}$$

subject to

$$\pi_1 + \pi_2 = 0 \tag{18}$$

Solving the above problem, the following **Lemma 1** is obtained.

Lemma 1: When the authority over the PDAM is impartially allocated, the unit price of water and network capacity in Region 1 and Region 2 are set as follows (see the APPDENDIX for the proof).

$$p^* = 1$$

$$n_1^* = 1 - a_1$$

$$n_2^* = 1 - a_2$$

In the process of proving **Lemma 1**, it is shown that the supplying capacities should be set to satisfy exactly the potential aggregate demand in each region. Redundant supplying capacity is always undesirable. Secondly, the zero profit constraint of PDAM requires the price to coincide with the marginal cost of water supply including two components of costs, i.e. c and c_f. In summary, when the authority over the PDAM is impartially allocated, the price of PDAM water is set at the level equivalent to the marginal cost of water supply. In addition, the supplying capacities in both regions cover the potential aggregate demand exactly.

(6) The case of partial authority allocation

This subsection is for analysis of the case when the authority over the PDAM is partially allocated to the Region 1 and Region 2 has no influence on the PDAM's decision. The government of Region 1 is benevolent in the sense that it represents the welfare of people exclusively in Region 1, attempts to minimize the aggregate cost of households to acquire water in Region 1. PDAM is in principle a public corporation. Hence, price is set at the level of cost recovery basis, i.e. the profit of PDAM must be zero.

Therefore, the price of PDAM water and network capacity in Region 1 and Region 2 are effectively set by the government of Region 1. The problem of the government in Region 1 is formulated as minimization of the total cost of water acquisition in Region 1.

$$\min_{p,n_1,n_2} TC_1 \tag{19}$$

subject to (18).

By solving the above optimization problem, the following **Proposition 1** is derived (see the APPENDIX for the proof).

Proposition 1: The government in Region 1 sets the price of PDAM water $p^{\circ} = 1$ and $n_1 = 1 - a_1$. Decision on n_2 does not have any influence on the welfare of Region 1 as long as it is $n_2 \in [0, 1 - a_2]$.

No-discrimination policy of water price will provides the authoritative government an incentive to set the price at the efficient level under the above setting. However, in the absence of the fixed cost, the government of Region 1 has no interest on the welfare of Region 2. This implies that the degree of shared fixed asset between two regions, partial ownership of water supply system may cause disregard of outside their territory. However, providing the PDAM water at the marginal cost level in Region 2 does not conflict with pursuing the welfare in Region 1.

4. FLUCTUATED DEMAND

(1) Assumption

The cost of using alternative water sources fluctuates depending on the season. In fact, private well and spring is easier to get short compared to river water which is the main source of PDAM. The previous section identified a principle that the supplying capacity has to fulfill the potential demand of PDAM water exactly. However, the supplying capacity is not variable depending on seasons. Therefore, the fluctuation of the potential demand for PDAM water makes it impossible to apply this '*fulfilling*' principle. Hence, the supplying capacity will be redundant in some season, whereas it may be strictly binding constraint in other seasons.

The aggregate demand for PDAM water in Region 1 is assumed to be

$$\begin{cases} \bar{x}_1^N(p) = 1 - a_1^N p & \text{normal season} \\ \bar{x}_1^D(p) = 1 - a_1^D p & \text{dry season} \end{cases} \tag{20}$$

i.e., $F_1^j(\rho) = a_1^j \rho \ (j = B, D)$ where $a_1^N > a_1^D$. For the simplicity of analysis, assume $a_1^D = a_2 = a$ and $a_1^N = \delta a$ where $\delta > 1$. The length of the dry season is denoted by γ and of the normal season $1 - \gamma$ where $0 \le \gamma \le 1$. The price of PDAM water is constant through a whole year once it is determined. The government of Region 1 decides the price of PDAM water and the water supply capacity in two regions to minimize the total cost spent for water usage.

The inverse demand function is also defined by the same manner as above.

$$\bar{P}_1^j(x_i) = \frac{1 - x_i}{a_1^j} \quad \text{for } j = N, D \tag{21}$$

$a_1^N > a_1^D$ implies $\bar{P}_1^N(n_1) < \bar{P}_1^D(n_1)$. Following the definition of 'real' aggregate demand function in Region 1 is

$$x_1^j(p, n_1) = \begin{cases} 1 - a_1^j p & \text{if } 1 - a_1^j p < n_1 \\ n_1 & \text{if } 1 - a_1^j p \ge n_1 \end{cases} \quad \text{for } j = N, D \tag{22}$$

It is assumed that

$$1 - a_1^N(c + c_f) \ge 0. \tag{23}$$

(2) The cost of water acquisition and the profit of PDAM

The total cost of water acquisition in Region 1 is fluctuated by the seasonal change of the availability of alternative water sources. Then the total cost of water acquisition in Region 1 in each season is represented by

$$TC_1^j = p x_1^j(p, n_1) + \int_0^{\max\left[p, \bar{P}_1^j(n_1)\right]} \rho \, dF_1^j(\rho) \quad \text{for } j = N, D. \tag{24}$$

Therefore, the total cost of water acquisition in Region 1 through a year is calculated as

$$TC_1 = \gamma TC_1^D + (1 - \gamma) TC_1^N. \tag{25}$$

On the other hand, the season-dependent cost for supplying PDAM water in Region 1 is

$$C_1^j = c x_1^j(p, n_1) + c_f \quad \text{for } j = N, D. \tag{26}$$

Therefore, the cost for PDAM water through a year is

$$C_1 = \gamma C_1^L + (1 - \gamma) C_1^H \quad \text{for } j = N, D. \tag{27}$$

For the analytical convenience, define

$$\theta_1^j = \frac{x_1^j(p, n_1)}{n_1} \tag{28}$$

that denotes the ratio of usage ratio against the capacity of pipeline. θ_1^j must be $0 \leq \theta_1^j \leq 1$. The cost of PDAM water supply C_i is written as

$$C_1 = m_1 n_1 \text{ and} \tag{29}$$

$$m_1 = \gamma m_1^D + (1-\gamma) m_1^N \tag{30}$$

$$m_1^j = \frac{\sigma_1^j + k}{1+k} \tag{31}$$

where $\sigma_1^j = 1/\theta_1^j (\geq 1)$. m_1^j is regarded as the apparent marginal cost of water supply in Region i in season j.

For the analytical convenience, define

$$M = 1 + \mu(m_1 - 1) \tag{32}$$

$$\mu = \frac{n_1}{n_1 + n_2}. \tag{33}$$

Using the above notation, the total profit of PDAM is written as

$$\pi = (p - M)(n_1 + n_2). \tag{34}$$

M is regarded as the apparent marginal cost of water supply in total. M is dependent on the price, the supplying capacity and the ratio of seasonal length.

(3) The case of impartial authority

By the same token in **3.**, the case of impartial authority requires the PDAM to minimize the sum of the total cost of water acquisition in Region 1 and Region 2. Hence the optimization problem is formulated as

$$\min_{p, n_1, n_2} TC_1 + TC_2 \tag{35}$$

subject to

$$\pi = 0 \tag{36}$$

For the simplicity of the analysis, assume $\delta a \approx 0$ and

$$\frac{1-\gamma}{\gamma} < (1+k)(\delta - 1) \tag{37}$$

Solving the above optimization problem, the following **Lemma 2** can be obtained (see APPDENXI for the proof)

Lemma 2: If the authority over PDAM is impartially allocated between Region 1 and Region 2, the price and the supplying capacity in each region is set as follows.

$$p^{**} > 1$$

$$1 - \delta a p^{**} < n_1^{**} \leq 1 - a p^{**}$$

$$n_2^{**} = 1 - a p^{**}$$

(37) is an assumption to guarantee that deviating the price from the marginal cost and extending the supplying capacity in Region 1 contributes to decreasing the total cost. If PDAM supplies water at price equivalent to the marginal cost, due to the zero profit constraint, PDAM water is insufficiently supplied in the dry season due to the shortage of pipelines. In order to relax the shortage of pipeline in the dry season in Region 1, price has to be increased to meet the balance of PDAM accounting. On the other hand, increase in price reduces the usage of water in the normal season in Region 1 as well as in Region 2. In addition, expanded network is redundant in the normal season. Therefore, some households in Region 1 do not use PDAM water in the normal season, hence no revenue from them to PDAM in the normal season. In fact, the profit coming from each region is

$$\pi_1 = (p - m_1) n_1 < 0 \tag{38}$$

$$\pi_2 = (p - m_2) n_2 = (p-1) n_2 > 0. \tag{39}$$

It means that Region 2 pays more than the marginal cost, whereas Region 1 pays less than that. It is interpreted that the surplus is transferred from Region 2 to Region 1 for the redundancy in Region 1.

The degree to what extent the surplus is transferred from Region 1 to Region 2 depends on the difference of availability of alternative water sources between in the dry season and the normal season, and the length of the dry season.

(3) The case of partial authority allocation

When the authority over the PDAM is partially allocated to the government of Region 1, the PDAM pursues minimizing the total cost of water acquisition in a year. Keep the assumption (37).

$$\min_{p, n_1, n_2} TC_1 \tag{40}$$

subject to (36).

Solving the above problem, the optimal choice of the Region 1 government is derived as shown in **Proposition 2** (see the APPENDIX for the proof).

Proposition 2 With the seasonal fluctuation of aggregate demand in Region 1, the price of PDAM water $p^{\circ\circ}$ and the supplying capacity in Region 1 and Region 2 $n_1^{\circ\circ}$, $n_2^{\circ\circ}$ satisfies

$$p^{\circ\circ} > p^{**}$$

$$n_1^{\circ\circ} > n_1^{**}$$

$$n_2^{\circ\circ} = 1 - p^{\circ\circ} < n_2^{**}$$

Proposition 2 implies that the price under the partial authority allocation leads to higher price than the partial price and the supplying capacity in Region 1 is more whereas that in Region 2 is less compared to the case of impartial authority allocation. The partial authority allocation is preferable for Region 1, but not for Region 2. Increase in the price generates surplus more from Region 2. The surplus in Region 2 is spent for the expanding the network capacity in Region 1 which enables to decrease the cost of water acquisition in Region 1 in the dry season due to the supplying capacity constraint.

Comparison of the case of partial authority allocation and impartial authority allocation tells us that the households in Region 2 are in a disadvantageous position. Firstly, Region 2 pays more than the cost spent for their PDAM water usage. Secondly, they could have enjoyed more usage of PDAM water if the price of PDAM water is served at the price on the cost recovery basis.

The **5.** discusses about the sources of that problem and suggestion of alternative policies to mitigate the problem.

5. DISCUSSIONS

(1) Externalities

The problem of partial authority allocation between the regions is a matter of *externalities* arising from unique attributes of the case that we assume for depicting the institutional environment in the water supply system in Bandung region. Fundamental assumptions set in the above analysis are summarized as follows:

1) The supplier of the networked water covers multiple jurisdictions because of the geological reason and the profit of water supplier is constrained to be zero.
2) No discrimination of water price between the regions
3) Asymmetricity in the availability of alternative water sources between the regions
4) The seasonal fluctuation of the networked water source

The assumption 1) is related to the issue of water rights and the economy of scale technology. If each region has plenty of raw water sources and there is no economy of scale, there is no economic reason that a supplier of networked water covers multiple jurisdictions. Although our model does not assume the economy of scale and water rights setting explicitly, the supplier's coverage of multiple jurisdictions can be justified by the technical assumption 1).

Assumption 2) is regarded as a political constraint rather than an economic constraint.

Assumption 3) and 4) is a necessary condition which generates a difference in the usage of supplying capacity between or among regions. The fluctuation regarding the availability of alternative water sources can make the redundancy of supplying capacity of pipeline. This is because pipelines cannot be adjusted to the volume of PDAM water usage. In this sense, an investment for pipelines is regarded as a fixed cost.

Our primary motivation of the study is to identifying the problem of partial authority allocation over the PDAM, the organization of water supply in Bandung region. Remind the case there. PDAM Tirta Raharj covers areas of several jurisdictions including Bandung Regency, the monopolistic owner of the authority over it and Cimahi City. Region 1 in the model is regarded as Bandung Regency and Region 2 as Cimahi City.

This difference is typically apparent between rural area (i.e. Bandung Regency) and urban area (i.e. Cimahi City). In Bandung Regency, with richer alternative water sources may not use the full supplying capacity of pipeline in the non-dry season.

Partial allocation of authority over the PDAM with multiple jurisdictions generates externalities under the above settings. According to the analytical result in **3.,** the price set under the partial authority allocation is efficient and the supplying capacity in the Cimahi City with less alternative water sources does not matter with the welfare in rural area. However, the analytical result in **4.** exhibits that introducing the fluctuated demand of PDAM water, hence the redundancy without the fluctuation of aggregate demand, is a source of externalities on Cimahi City.

Bandung Regency less suffers from the increase of price than Cimahi City as the former has richer access to alternative water sources other than PDAM water. Rather the interest of Bandung Regency is expanding the supplying capacity which is constrained in the dry season. Therefore, Bandung Regency is tempted to expand the supplying capacity in their territory by increasing the revenue of PDAM. As the increase of PDAM water generates surplus from Cimahi City which can be utilized by Bandung Regency, Bandung Regency will use the surplus for expanding the supplying capacity in its own territory.

(2) Policy implication

Externalities can be overcome by an efficient negotiation according to the Coasian theorem[9]. It tells us that any externalities can be internalized by an efficient negotiation among stakeholders regardless of the initial allocation of ownerships or authorities. Therefore, according the Coasian theorem, Cimahi City may motivate to ask Bandung Regency to decrease the price of water and to expand the supplying capacity in Cimahi City by direct money transfer from Cimahi City to Bandung Regency.

However, the Coasian theorem concerns only with the economic efficiency and not with the fairness aspect. The fact that Cimahi City joins a negotiation process with Bandung Regency itself implies that Cimahi City accepts the current regime of partial authority allocation over the PDAM. But people in Cimahi City will not accept such a negotiation to avoid accepting the partial authority allocation as an accomplished fact.

Failure of efficient negotiation between Cimahi City and Bandung Regency implies the necessity of intervention of higher rank of authority like the provincial government and the national government. Although a governing system encompassing the provincial government is out of the scope of the study here, the above-identified problem will not be solved unless the provincial government aware of its own role in coordinating the interests of local governments such as Cities and Regencies.

6. CONCLUSION

The partial authority allocation over the networked water facility system in Indonesia is a consequence of the decentralization policy in 2001. Our analysis shows that the partial authority allocation can be problematic when the regional asymmetricity regarding the availability of alternative water sources and the seasonal fluctuation exists. The price of the networked water is more expensive than the efficient level and the investment for pipelines in the urban area is insufficient, whereas that in the rural area is excessive. Hence, the insufficient penetration of PDAM water in the urban area is partly contributed by the current regime of partial allocation of authority over the PDAM.

In addition, we have pointed out that negotiation for solving the problem will not work due to the political reason. This kind of partiality problem must be solved by higher rank of government system such as the provincial government and the central government.

ACKNOWLEDGMENT: We thank Mr. Hery Antasari and staff, from Bapeda Cimahi City Local Government, and Ms. Hendriati from PDAM Tirta Raharja. We are also very thankful to Dr. Ibnu Syabri, and his colleagues in School of Architecture, Planning and Policy Development ITB, Bandung.

APPENDIX PROOF OF PROPOSITIONS

(Proof of Lemma 1)

Firstly, consider a point (p, n_1, n_2) that satisfies (18) and $p > \bar{P}_i(n_i)$, i.e. the capacity is not constrained. In this case, cutting the supplying capacity does not change the total cost of water acquisition. Cutting the supplying capacity generates the surplus for PDAM which enables to decrease the price of water and to use the redundant supplying capacity since (15) holds. Therefore, any (p, n_1, n_2) which satisfies $p > \bar{P}_i(n_i)$ cannot be optimal.

Secondly, a point (p, n_1, n_2) that satisfies (18) and $p \leq \bar{P}_i(n_i)$ or $m_i = 1$, i.e. the capacity is strictly constrained. The zero profit constraint of PDAM (18) is written as

$$(p-1)(n_1+n_2) = 0 \tag{41}$$

When $n_1 + n_2 \geq 0$, the zero profit constraint requires $p = 1$.

Then the problem is reformulated as the problem of optimizing the supplying capacity n_1 and n_2 for minimizing the total cost of water acquisition given $p = 1$ and $p \leq \bar{P}_i(n_i)$, where zero profit constraint always holds.

If $\bar{P}_i(n_i) \geq 1$, the associated change of the total cost of water acquisition due to the small change in the supplying capacity is derived as

$$\begin{aligned} &d(TC_1 + TC_2) \\ &= \{1 - \bar{P}_1(n_1)\}dn_1 + \{1 - \bar{P}_2(n_2)\}dn_2 \end{aligned} \tag{42}$$

It is apparent that as long as $\bar{P}_1(n_1) \geq 1$ and $\bar{P}_2(n_2) \geq 1$, the small change in the supplying capacity contributes to reducing the total cost of water acquisition. In addition, $\bar{P}_i(n_i)$ is monotonically decreasing in the supplying capacity n_i. Therefore, the total cost of water acquisition is minimized when $\bar{P}_1(n_1) = 1$ and $\bar{P}_2(n_2) = 1$ holds.

(Proof of Proposition 1)

Only the difference between the problem of partial authority allocation and the impartial authority allocation is just the objective function. The logic of proof is fundamentally same as the one of **Lemma 1**.

$$dTC_1 = \{1 - \bar{P}_1(n_1)\}dn_1 \tag{43}$$

The minimizing the objective function, i.e. the total cost of water acquisition in Region 1 requires $\bar{P}_1(n_1) = 1$. However, the supplying capacity in Region 2 n_2 is not relevant to the objective of PDAM controlled by the government in Region 1.

(Proof of Lemma 2)

Firstly, consider a point (p, n_1, n_2) that satisfies (36) and $p > \bar{P}_1^D(n_1)$ and $p > \bar{P}_2(n_2)$, i.e. the capacity is not constrained in any seasons. In this case, cutting the supplying capacity does not change the total cost of water acquisition. Cutting the supplying capacity generates the surplus for PDAM which enables to decrease the price of water and to use the redundant supplying capacity since (15) holds. Therefore, any (p, n_1, n_2) which satisfies $p > \bar{P}_1^D(n_1)$ and $p > \bar{P}_2(n_2)$ cannot be optimal.

Secondly, a point (p, n_1, n_2) that satisfies (36) and $p \le \bar{P}_1^N(n_1)$ and $p \le \bar{P}_2(n_2)$, i.e. the supplying capacity is constrained in any season. In this case, $m_1 = m_2 = 1$ holds and the zero profit constraint (36) is written as

$$(p-1)(n_1+n_2) = 0. \tag{44}$$

When $n_1 + n_2 \ge 0$, the zero profit constraint requires $p = 1$. Following the same logic used in the proof of **Lemma 1**, $\bar{P}_1^N(n_1) = 1$ and $\bar{P}_2(n_2) = 1$ holds.

Thirdly, a point (p, n_1, n_2) that satisfies (36) and $\bar{P}_1^N(n_1) \le p \le \bar{P}_1^D(n_1)$ and $p \le \bar{P}_2(n_2)$, i.e. the supplying capacity is constrained in the dry season, but redundant in the normal season. In this case, $m_1 \le 1$ holds.

$$\pi = (p - M)(n_1 + n_2). \tag{45}$$

When $n_1 + n_2 \ge 0$, the zero profit constraint requires $p = M$. Contrary to the case of $p \le \bar{P}_1^N(n_1)$ and $p \le \bar{P}_2(n_2)$, expanding the supplying capacity is accompanied by the associated change in the apparent marginal cost M. Note The $m_1^D = 1$ and $m_1^D \le 1$. The associated change in M due to the small change in supplying capacity n_1 is

$$\frac{\partial M}{\partial n_1} = \frac{\partial \mu}{\partial n_1}(m_1 - 1) + \mu \frac{\partial m_1}{\partial n_1}$$

$$\frac{\partial \mu}{\partial n_1} = \frac{n_2}{(n_1+n_2)^2} (> 0)$$

$$\frac{\partial m_1}{\partial n_1} = (1-\gamma)\frac{\partial m_1^N}{\partial n_1}$$

$$\frac{\partial m_1^N}{\partial n_1} = \frac{1}{1+k}\frac{\partial \sigma_1^N}{\partial n_1}$$

$$\frac{\partial \sigma_1^N}{\partial n_1} = \frac{1}{x_1^N(p, n_1)} > 0$$

Hence the small change in the supplying capacity always induces the increase of the apparent marginal cost M.

$$\frac{\partial M}{\partial n_2} = \frac{\partial \mu}{\partial n_2}(m_1 - 1)$$

$$\frac{\partial \mu}{\partial n_2} = -\frac{n_1}{(n_1+n_2)^2} (< 0)$$

The small change of the price also induces the change of the apparent marginal cost.

$$\frac{\partial M}{\partial p} = \mu \frac{\partial m_1}{\partial p} \tag{46}$$

$$\frac{\partial m_1}{\partial p} = (1-\gamma)\frac{\partial m_1^N}{\partial p} \tag{47}$$

$$\frac{\partial m_1^N}{\partial p} = \frac{1}{1+k}\frac{\partial \sigma_1^N}{\partial p} \tag{48}$$

$$\frac{\partial \sigma_1^N}{\partial p} = \frac{a_1^N}{\{x_1^N(p, n_1)\}^2} > 0 \tag{49}$$

Hence the small change in the price always induces the increase of apparent marginal cost M.

In addition, the second-order of the marginal change of M due to the small change of p is

$$\frac{\partial^2 M}{\partial p^2} > 0 \tag{50}$$

As the price increases, the associated change of M becomes larger.

Consider the objective function. When $\bar{P}_1^N(n_1) \le p \le \bar{P}_1^D(n_1)$ holds,

$$TC_1^N = p\bar{x}_1^N(p) + \int_0^p \rho dF_1^N(\rho) \tag{51}$$

$$TC_1^D = pn_1 + \int_0^{\bar{P}_1^D(n_1)} \rho dF_1^D(\rho) \tag{52}$$

Hence,

$$\frac{\partial TC_1^N}{\partial p} = \bar{x}_1^N(p), \qquad \frac{\partial TC_1^D}{\partial p} = n_1 \tag{53}$$

$$\frac{\partial TC_1^N}{\partial n_1} = 0, \qquad \frac{\partial TC_1^D}{\partial n_1} = p - \bar{P}_1^D(n_1) \tag{54}$$

Total differentiation of objective function is

$$\frac{\partial TC_1}{\partial p} = (1-\gamma)\bar{x}_1^N(p) + \gamma n_1 \tag{55}$$

$$\frac{\partial TC_1}{\partial n_1} = -\gamma(\bar{P}_1^D(n_1) - p), \frac{\partial TC_1}{\partial n_2} = 0 \tag{56}$$

$$\frac{\partial TC_2}{\partial p} = n_2 \tag{57}$$

$$\frac{\partial TC_2}{\partial n_1} = 0, \frac{\partial TC_2}{\partial n_2} = -(\bar{P}_2(n_2) - 1) \tag{58}$$

The Lagrangian is defined as

$$\mathcal{L} = TC_1 + TC_2 - \lambda(p - M) \tag{59}$$

The first-order condition is

$$\frac{\partial \mathcal{L}}{\partial p} = \frac{\partial TC_1}{\partial p} + \frac{\partial TC_2}{\partial p} - \lambda\left(1 - \frac{\partial M}{\partial p}\right) = 0 \tag{60}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial n_1} &= \frac{\partial TC_1}{\partial n_1} + \frac{\partial TC_2}{\partial n_1} + \lambda\frac{\partial M}{\partial n_1} \\ &= \frac{\partial TC_1}{\partial n_1} + \lambda\frac{\partial M}{\partial n_1} = 0\end{aligned} \tag{61}$$

As

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial n_2} &= \frac{\partial TC_1}{\partial n_2} + \frac{\partial TC_2}{\partial n_2} + \lambda\frac{\partial M}{\partial n_2} \\ &= \frac{\partial TC_2}{\partial n_2} + \lambda\frac{\partial M}{\partial n_2} \leq 0\end{aligned} \tag{62}$$

is always satisfied, $p = \bar{P}_2(n_2)$ must hold.

Now consider the case that $p = 1$, $\bar{P}_1^N(n_1) = 1$ and $\bar{P}_2(n_2) = 1$, i.e. $x_1^N(p, n_1) = n_1 = 1 - a_1^N$, $x_2(p, n_2) = n_2 = 1 - a_2$ and $m_1 = 1$ holds. In that case,

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial p} &= (1 - \delta a) + (1 - a) \\ &-\lambda\left(1 - \frac{\mu(1-\gamma)\delta a}{(1+k)(1-\delta a)^2}\right)\end{aligned} \tag{63}$$

$$\frac{\partial \mathcal{L}}{\partial n_1} = -\gamma(\delta - 1) + \frac{\lambda\mu(1-\gamma)}{(1+k)(1-\delta a)} \tag{64}$$

When (37) holds, for λ which satisfies $\partial\mathcal{L}/\partial p = 0$, $\partial\mathcal{L}/\partial n_1 < 0$. It means that the increase of the supplying capacity and the increase the price decrease the total cost of water acquisition. Therefore, when the first-order condition (60) - (62) is satisfied, $p^{**} > 1$, $\bar{P}_1^N(n_1) < p^{**} \leq \bar{P}_1^D(n_1)$ and $\bar{P}_2(n_2) = p^{**}$.

(Proof of Proposition 2)

The logic of the proof is basically same as that for **Lemma 2**. Again, $p > \bar{P}_1^D(n_1)$ and $p > \bar{P}_2(n_2)$ cannot be the optimal. When $p \leq \bar{P}_1^N(n_1)$ and $p \leq \bar{P}_2(n_2)$, the zero profit constraint requires $p = 1$. Then, $\bar{P}_1^N(n_1) = 1$ is optimal. But as in the **Proposition 1**, any $n_2 \in [0, 1 - a_2]$ is optimal.

Thirdly, a point (p, n_1, n_2) that satisfies (36) and $\bar{P}_1^N(n_1) \leq p \leq \bar{P}_1^D(n_1)$ and $p \leq \bar{P}_2(n_2)$, the Lagrangian is written as

$$\mathcal{L} = TC_1 - \lambda(p - M). \tag{65}$$

Then the first-order condition is

$$\frac{\partial \mathcal{L}}{\partial p} = \frac{\partial TC_1}{\partial p} - \lambda\left(1 - \frac{\partial M}{\partial p}\right) = 0 \tag{66}$$

$$\frac{\partial \mathcal{L}}{\partial n_1} = \frac{\partial TC_1}{\partial n_1} + \lambda\frac{\partial M}{\partial n_1} = 0 \tag{67}$$

As

$$\frac{\partial \mathcal{L}}{\partial n_2} = \frac{\partial TC_1}{\partial n_2} + \lambda\frac{\partial M}{\partial n_2} < 0 \tag{68}$$

is always satisfied for any $\lambda > 0$, $p = \bar{P}_2(n_2)$ holds.

Comparing (60) and (66), the difference in the first-order condition between the case of partial authority allocation and that of impartial authority allocation is the exclusion of the effect of the price change on the total cost of water acquisition in Region 2, i.e. $\partial TC_2/\partial p$. As $\partial TC_2/\partial p > 0$ is holds, the optimal price $p^{\circ\circ}$ is always larger than the optimal price under the case of impartial allocation p^{**}.

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