Residential Water Use: Efficiency, Affordability, and Price Elasticity

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Abstract

In practice, water pricing is the main economic instrument used to discourage the wasteful use of residential water. Owing to considerations of affordability, residential water is systematically underpriced because water is essential for life. Such a low price results in water being used inefficiently. This paper proposes a system that supplements the existing price system with a cap-and-trade measure to reconcile conflicts among the goals of residential water use. It forces all people (independent of income) to be faced with reasonable price signals and to use water efficiently. The poor could, however, gain from trade and afford water. By taking advantage of the agent-based model, a simulation of this system applied to Taipei, Taiwan shows that those with lower income per capita are better off under this system even though the equilibrium price of residential water is higher. The simulated price elasticity of market demand is -0.438.

Keywords: residential water; efficiency; affordability; water pricing; cap and trade; price elasticity; agent-based model.

JEL classification: Q21; Q25; Q28

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1. Introduction

Water is essential for life. The supply of water is, however, insufficient and it is becoming increasingly scarce in terms of meeting all of the demand for it (WWDR2, 2006). Economic and population growth, urbanization, and pollution intensify the demand pressure, while freshwater supplies remain constant and are distributed unevenly in terms of space and time. Climate change is also having a significant impact on the precipitation and hydrological cycles, which makes the availability of surface water even more uncertain. Under these conditions, it is essential for water to be used efficiently.

Among all water uses, this paper will focus on the demand side in the case of residential water. Since the water supply for domestic use in general takes priority over other water usages, other water uses will be inefficient if residential water is not used efficiently. Around the world, water pricing is the main economic incentive instrument used to charge for residential water and to discourage its wasteful use.[1] There is a large literature that has studied the estimation of residential water demand and has mainly focused on the estimation of price elasticity. Different issues regarding the estimation have been explored, including the

[1] "Two scarcity-addressing strategies dear to water resource economists are water marketing and water pricing. *Marketing* is a management policy for natural water, whereas *pricing* pertains to partially- or fully-processed (retail) water." (Griffin, 2006, p. 203). There are many existing rate systems for water utilities both in theory and practice such as flat pricing, marginal cost (MC) pricing, average cost (AC) pricing, the rate-of-return regulation, Ramsey pricing, peak-load pricing, block-rate pricing, price-cap regulation, spot market pricing, and effective water pricing (see Zarnikau, 1994 and Griffin, 2001). In general, if the pricing system has or tends to have the characteristic of MC pricing, it results in a higher economic efficiency. However, because the water utility is basically a natural monopoly, it will experience a loss under MC pricing and will exit the market in the long run. Instead, if the pricing system has or tends to have the characteristic of AC pricing, the natural monopoly will not experience a loss, but the economic efficiency of the society will be lower. In addition, the water utility might produce water inefficiently because its costs can be recovered anyway (see, e.g., Burgess, 1995 and Viscusi et al., 2000).

following topics: whether the average or the marginal price combined with the difference variable should be used as the price variable in the demand equation (see, e.g., Taylor, 1975; Nordin, 1976; Foster and Beattie, 1979, 1981a, 1981b; Billings and Agthe, 1980; Billings, 1982; Nieswiadomy and Molina, 1989; Nieswiadomy, 1992; Renwick and Archibald, 1998; Shin, 1985; Opaluch, 1982; 1984; Taylor et al., 2004), model specification and functional forms of the demand equation (linear, logarithmic, Stone-Geary, or discrete/continuous choice models among others) (see, e.g., Gaudin et al., 2001; Martínez-Espiñeira and Nauges, 2004; Hewitt and Hanemann, 1995; Olmstead et al., 2007; Olmstead, 2009), the meta-analysis of various research estimates (see Espey et al., 1997; Dalhuisen et al., 2003), and country case studies (see, e.g., Martínez-Espiñeira, 2003; Reynaud et al., 2005; Schleich and Hillenbrand, 2009; Miyawaki et al., 2011; Rinaudo et al., 2012). In comparison with the above research, literature that studies institutional reforms of residential water management is relatively small and mainly focuses on the pricing system design (see e.g., Elnaboulsi, 2001; Hall, 2001; Boland and Whittington, 2001; Krause et al. 2003; García-Valiñas, 2005; Barberán and Arbués, 2009).

Charging for water serves multiple purposes regarding water use, including the user pays principle, equity and efficiency in water use, an increase in quality, the financial soundness of the water utility, and affordability for the poor. However, these purposes are not reconciled. For example, a higher price may increase the efficiency of water use and utility revenue, but it may also make water unaffordable to the poor. Owing to the consideration of affordability and the pressure from the demand side,[2] water is "systematically underpriced by suppliers" (Griffin, 2006) and the price cannot reflect all the costs of producing it.[3] The lower price causes water to be used inefficiently and renders its production costs irrecoverable.

Differing from the above reforms in the use of pricing systems, this paper proposes a price-cum-trade incentive system (PTS hereafter) to reconcile the multiple purposes of residential water use (in particular efficiency and affordability). Nowadays, cross-subsidization is generally applied by the regulator to harmonize the dilemma. Under this measure, the water utility charges low income groups and most residences below-average rates, but charges industrial and commercial users above-average rates to make up the difference. There are, however, some problems which may arise from the cross-subsidization. First, a cross-subsidy policy sends wrong signals to both the utility and consumers. The over-consumption by subsidized customers and the loss of sales to the subsidizing customers are both inefficient and result in welfare losses to the society. Second, such a policy violates the principle of fairness. In addition, cross-subsidization frequently leads to serious financial losses for utility companies (Yepes, 1999). "Raising tariffs is an option, but it is difficult in practice to set cost recovery tariffs." (Komives, 2004).

[2] Consumers always hope to enjoy a higher consumer's surplus regardless of whether they are poor or rich.
[3] In addition to the very high fixed costs of water utilities, the opportunity cost of using water instead of leaving it for environmental services should also be considered.

The PTS is based on the existing price-incentive system but also allows the water users to trade the water rights to which they are entitled. The PTS has the following positive characteristics. First, a cap design of residential water is used to take environmental sustainability into consideration.[4] Second, the allocation of initial water rights to individuals can be used to take equity into account. Third, trading forces everyone, regardless of whether they are rich or poor, to face the market equilibrium price – the right price signal for water. However, the affordability problem disappears. This is because the one who uses less (more) water than he or she is entitled to use can earn (spend) money by selling (buying) extra water at the market price. Facing a higher price, a poor person can either save water to sell and make money, or he can pay the existing price to use the water to which he is entitled (he is no worse off than under a pure price system). In addition, because the poor and water-saving people can earn money, the problems of resistance to higher water price and systematic under-pricing are alleviated. Forth, under the PTS, the market equilibrium price can adjust on its own quickly and flexibly to reflect changes in the scarcity of water. However, under the price system the regulator needs to have perfect information in order to set the optimal price system and these prices are not easily adjustable. Fifth, the water utility could benefit by drawing a share of the trade balance as its revenue.

In this paper, we also use a survey data set at the household level for Taipei, the capital

[4] Regarding the discussion of environmental sustainability of residential water, see Krause et al. (2003).

of Taiwan, to specify an agent-based model in order to study the application of the PTS system.[5] By using the agent-based model, we simulate the market equilibrium price of residential water and discuss the change of the income distribution of households. The simulated data for price and quantity are further used to estimate the price elasticity of market water demand. These research results are seldom studied in existing papers and can provide insights for residential water management.

In the next section, we shall describe the design of the price-cum-trade incentive system and analyze its characteristics of efficiency, affordability as well as its practicality. In Section 3, the agent-based PTS model is specified. The price elasticity of residential water demand is estimated and the post-trading income distribution of households is explored. Lastly, in Section 4 we provide the conclusion.

2. The price-cum-trade incentive system

We design the PTS as follows:

1. Suppose that under the existing price system, the unit water price is P_0.[6]
2. The minimal level of water supply for basic life support per capita, the basic water requirement, is $\underline{q}$, which cannot be traded.

[5] Agent-based modeling is a computational method for simulating the actions and interactions of autonomous agents. It is one of the complementary methods used to solve complex and un-computable problems. For more information, please visit this website (http://www.econ.iastate.edu/tesfatsi/).

[6] For simplification, we adopt a flat price case for ease of explanation. Different rate structures can be applied as well.

3. Suppose that the cap of residential water is $\overline{Q}$, which is converted to a corresponding amount of water rights.[7]

4. The regulator allocates $\overline{Q}$ to individual water users, who are denoted by $i = 1,\ldots,n$. Suppose that each individual water user obtains $\overline{q}^i$ units of rights, $\sum_{i=1}^{n} \overline{q}^i = \overline{Q}$. It should be noted that $\overline{q}^i$ is a usufructuary right. By this we mean that $\overline{q}^i$ is not a property right. A water user should pay the unit price P_0 to enjoy the water to which he is entitled by the right.

5. Individual water users can trade $\overline{q}^i$ with each other freely. When the market equilibrium price $P^* > P_0$, the user who sells his usufructuary rights can earn a profit from the price spread ($P^* - P_0$).

6. The compliance condition for an individual water user at the end of each period is: $\underline{q} \leq$ the amount of water he consumed $\leq$ the amount of water rights he owns.

Let us examine the PTS in detail. First, $\overline{Q}$ is the cap for residential water which is usually determined by the total amount of water rights for residential use. $\overline{Q}$ can be used to consider the environmental value and sustainable use of water as well. When water is scarcer, for example, the regulator could set a smaller amount of $\overline{Q}$. The market equilibrium price will therefore be higher and reflect the scarcity of water. In general, the existing price systems could not reflect the actual value of water appropriately and flexibly.

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[7] Suppose that one unit of water rights deserves one unit of water.

The initial allocation of $\overline{Q}$ is related to the income distribution but unrelated to efficiency. There are different users competing for water, such as families, businesses, organizations, schools, city-administrations, and others. If $\overline{Q}$ is less than the existing total amount of water usage, how then could $\overline{Q}$ be appropriately allocated among competing users? One of the feasible ways is to proportionately reduce the various water usages in the status quo. Then these initial water rights are further allocated to individuals. For family water consumption, the initial quantity might be allocated equally to every person. For business water consumption, the initial allocation might again be based on a proportionate reduction. Of course, every society could apply its own appropriate approach to allocate water.

Second, water is systematically underpriced in practice regardless of the price systems adopted. The PTS can, however, help force everyone to face a higher market price while the poor are made better off. This is demonstrated in Figure 1, which is a simple example with two water users. In Figure 1, the demand curves for water for users 1 and 2 (D_1 and D_2) are drawn from the left-hand and right-hand axes, respectively. The cap of residential water is $\overline{Q}$ and the existing unit water price is P_0. At P_0, the water demanded by users 1 and 2 are q_0^1 and q_0^2, respectively. It is easily seen that $q_0^1 + q_0^2 > \overline{Q}$. Supposing that $\overline{Q}$ is an appropriate amount of water which takes into account the sustainable use, the above inequality then indicates that the price of residential water is not sufficiently high to allow the water to be used efficiently.

If the regulator somehow allocates $\overline{Q}$ equally to users 1 and 2, i.e., $\overline{q}^1 = \overline{q}^2 = \overline{Q}/2$, at the quota $\overline{Q}/2$, the marginal willingness to pay of user 2 (A_2) is higher than that of user 1 (A_1). Both users therefore have an incentive to trade. The trading would take place until the marginal willingness to pay of each user is equal. At point Q^*, the water market is in equilibrium. If user 1 is poor, we see that he could earn a profit of $(P^* - P_0)*(\overline{Q}/2 - q_1^1)$ by saving and selling water.[8] A very important part of the trade is that both the rich and the poor face the correct price signal and both gain from trade. A correct signal would force people to use water efficiently and save water. In addition, the regulator does not need any information to set the equilibrium price. This is, however, a difficult task under a pure price system.[9]

In the long run, because people would improve their household appliances to save water (either to earn money or to reduce water expenditure), the total amount of water used by the society will decrease. Moreover, the water industry might possibly be further developed because of the commonly active water saving behavior of people.[10]

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[8] In a drought, if the regulator could further allow the domestic water users to trade with other water users (industrial users, for example), these other users might also be able to benefit from trade. Under this situation, the equilibrium price would be even higher because the demand for water would increase. The buyer, user 2 in the above example, might decide instead to become a seller.

[9] Existing rates are generally dependent on historical data and are very difficult to adjust to reflect the current situations because of the considerations of affordability for the poor, political commitments, and pressure from water users (the pressure is even higher when the overall economic situation is aggravated).

[10] Governments usually apply measures which encourage the renewal of water-saving facilities in government and schools to help save water and to promote the water industry. Such measures do not influence people's customs when using water, however. People are only passive when saving water and the development of the water industry heavily depends on subsidy from the government.

3. The agent-based PTS model

In this section, we will specify an agent-based PTS model based on a survey data set at the household level to study the practicability of the PTS and discuss the market equilibrium, income distribution, and price elasticity. We will first describe the data set and use the Stone-Geary utility function to take into account major demand variables including the subsistence level of water use, the water price, and the ratio of water expenditure to disposable income. The estimated water demand equation is then used to calibrate the water use behavior of the household which is defined as a household agent. The discussions of equilibrium, income distribution, and price elasticity follow thereafter.

3.1 Data description

The data used in this paper consist of the original sampling data from the "Report on the Family Income and Expenditure Survey" in Taipei, Taiwan.[11] The survey is a nationwide questionnaire completed annually by Taiwan's central and local governments and contains data on income, household characteristics, and water expenditure, etc., all at the household level. It is interesting to study the case of Taiwan because water is in fact a scarce resource in Taiwan and thus ought to be used very efficiently.[12] The price system for residential water is,

[11] Taiwan is a newly-industrialized Asian economy with a population of 22.77 million persons and a GDP per capita based on purchasing-power-parity (PPP) of US$ 27572.22 in 2005 (see the World Economic Outlook Database, International Monetary Fund).

[12] Taiwan is mountainous and the distributions of rainfall and runoff are very uneven. Rivers are also relatively short and steep so that the precipitation is very hard to store for subsequent utilization. The groundwater is overused which has resulted in the problem of land subsidence in some places. Since there is a large population,

however, one that is under-priced and has not been adjusted since 1994. The lower water price system not only results in inefficient water use, but the goals of financial soundness in terms of water utility, equity, and environmental sustainability can not as a result be attained.[13]

In the whole original sample, we use the data of Taipei City for the year 2005. This is mainly because, unlike other cities, Taipei's data on residential water expenditures can be distinguished from domestic waste treatment fees in this year. In addition, almost all people in Taipei are served by tap water (the percentage of population served was 99.5% in 2005). Based on this survey, after removing missing data and outliers we have data for 1,985 households. Due to the fact that water billing accumulates bimonthly, we rescale our data into bimonthly form. Table 1 presents the bimonthly average statistics of disposable income, water consumption, and water expenditure per household by disposable income quintile.[14] Figures show that households with higher disposable income consume more water and pay more for water. The water expenditure share of disposable income, however, exhibits a reversed pattern in that the ratio is lower for higher-income households.

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the annual available water per capita (TARWR per capita 2005) in Taiwan is only 2930 m^3/year (see Table 4.3 in WWDR2, 2006).

[13] The amount of water used in Taipei is 352 liters per capita per day, which is the second highest amount among approximately 100 cities surveyed by IWA (2008).

[14] The figures for water consumption are calculated from the data on water expenditure and the rate structure for tap water in Taipei (see Appendix 1). There are two data adjustments that should be noted. First, in practice, a sewer fee of 5 NT$ is charged for each cubic meter of water consumption in addition to the unit fee of water. This sewer fee is considered in this paper. Second, the magnitude of fixed cost is related to the diameter of the water meter. Because we don't have this data for each household, we assume that the diameter form of the meter applied by all households is 20mm, which is the most popular form (its share is 46.34%).

3.2 The Stone-Geary demand function

In the following, we use the Stone-Geary utility function to derive and estimate the water demand function. The Stone-Geary utility function is

$$U = (q_w - \gamma_w)^{\alpha}(q_y - \gamma_y)^{1-\alpha},$$

where U denotes the level of utility, q_w and q_y are respectively the consumption of water and the composite good, α is the ratio of water expenditure to disposable income, and γ_w and γ_y represent the subsistence consumptions of water and the composite good, respectively. In considering the individual household disposable income I, water price p_w, and the price of the composite good p_y, we derive the following optimal consumption bundle of water:

$$q_w = \gamma_w + \frac{\alpha}{p_w}(I - \sum_{\forall k} p_k \gamma_k),$$

in which $k = \{w, y\}$. By assuming the composite good is the numeraire ($p_y = 1$) and letting $\gamma_y = 0$ to focus on water consumption, we can simplify the above consumption bundle to

$$q_w = \gamma_w + \frac{\alpha}{p_w}(I - p_w\gamma_w) = (1-\alpha)\gamma_w + \alpha\frac{I}{p_w}.$$

The main advantages of the Stone-Geary specification are that the estimated elasticities are non-constant and it uses only two parameters which have economic meaning: α, which is the marginal budget share of water, and γ, which represents a threshold below which consumption may not be responsive to prices (see Gaudin et al., 2001; Martínez-Espiñeira and Nauges, 2004).

In this paper, average price is treated as the price variable and is obtained as a result of dividing water expenditure by water consumption. Average price, and not the marginal price combined with the difference variable, is used because the price system as applied in Taipei is complicated. This price system consists of a fixed fee and five increasing block rates. In addition, the cost of water is relatively low compared to disposable income.[15] This paper also explicitly considers some water-use-related variables for household characteristics such as the number of household members (*N*), house size (*H*), and the education level of the householder (*EDU*). The data descriptions for variables at the household level are presented in Table 2. The estimate of the water demand equation yields (t-ratio in parentheses):

$$q_w = \underset{(5.148)}{13.722} + \underset{(10.291)}{0.00081}\frac{I}{p_w} + \underset{(11.923)}{6.49}\,N + \underset{(3.567)}{0.2}\,H + \underset{(0.519)}{0.176}\,EDU + \varepsilon\,, \quad \overline{R}^2 = 0.24$$

According to the estimates, the threshold (or subsistence level) of water is calculated as 13.733 (= 13.722/(1– 0.00081)) cubic meters per household bimonthly and the minimal daily water consumption per person is about 72.66 liters.[16] The estimated price elasticity (η_p) and

[15] "Conventional consumer theory assumes that users have perfect information about their preferences and constraints. They are assumed to react to changes in marginal prices and not to changes in intramarginal prices, because the former give rise to a substitution effect while the latter are assumed to create only an income effect. However, under high relative costs of information on the tariff, water users might respond more to average price changes than to marginal price changes (Foster & Beattie 1981a, 1981b; Nieswiadomy 1992) by obtaining information on the total bill and the total amount consumed and roughly calculating an average price. Extra effort would be needed to learn about the marginal price. Calculating the marginal price from a bill in the presence of pricing blocks is not easy, and calculating which block consumers are consuming in (and therefore which marginal price they are facing) is even more difficult. This might not be considered worthwhile, especially since the relative cost of water is low compared to income." (p. 238 in Martínez-Espiñeira, 2003)

[16] The minimal daily water consumption per person of 72.66 liters is calculated by transferring 13.733 cubic meters to liters first and then dividing 13733 liters per household bimonthly by 60 (days) and 3.15 (average number of persons per household). There are different suggestions for the basic water requirement in the literature. For example, WELL (1998) and WHO and UNICEF (2000) suggested a reasonable minimum as being 20 liters per capita per day; Gleick (1996, 1998) recommended an overall basic water requirement of 50 liters per capita per day. In Howard and Bartram (2003), 100 liters per capita per day and above is the optimal access.

income elasticity (η_I) at the sample mean are -0.22 and 0.22, respectively. They have the same magnitude and opposite signs and can be derived by $\eta_p = -\eta_I = -\alpha(I / p_w q_w)$. The price elasticity shows that the water demand is not very sensitive to the water price. This finding might be due to the relatively low water price and its small variation. It is consistent with the estimates suggested by existing empirical studies.[17]

3.3 The agent-based water rights market and income distribution

In this subsection, we simulate the scenario in which the PTS is applied in Taipei by using the agent-based PTS model. Here, a "household" is defined as an agent. The Stone-Geary water demand equation and bimonthly household data are used to calibrate individual household behavior. The market-clearing water price is determined when total water rights ($\bar{Q}$) equal total water demand, which can be formulated as the following equation:

$$\bar{Q} = \sum_{i=1}^{n} \bar{q}^i = \sum_{i=1}^{n} q_w^i(p_w) \text{ ,}$$

where $q_w^i(p_w)$ is the individual water demand function which is represented by the above estimated Stone-Geary water demand equation and $\bar{q}^i$ is the water right allocated to the *i*th

[17] Based on a review of 24 journal articles published between 1967 and 1993, Espey et al. (1997) indicated that the price elasticity estimates range from -0.02 to -3.33 in the sample, with an average of -0.51. About 90% of the estimates are between 0 and -0.75. Dalhuisen et al. (2003) reviewed 64 studies that appeared between 1963 and 2001. The distribution of price elasticities has a sample mean of -0.41, a median of -0.35, and a standard deviation of 0.86. The minimum and maximum values are -7.47 and 7.90, respectively. The distribution of income elasticities has a mean of 0.43, a median of 0.24, and a standard deviation of 0.79. Approximately 10% of the estimates are greater than 1. A more recent survey paper, Worthington and Hoffman (2008), indicates that price elasticity estimates are generally found in the range of zero to 0.5 in the short run and 0.5 to unity in the long run; income elasticity estimates are of a much smaller magnitude (usually) and positive.

individual household. For simplicity in analysis, we assume that the $\bar{Q}$ are rationed equally among individuals (regardless of whether they are young or old, rich or poor persons). In the status quo of the data set, the total amount of water consumed is 107,808 cubic meters. Each person is allocated 17.241 cubic meters of water rights bimonthly.[18] Households will purchase water rights when their respective water demand exceeds the allocated water rights at the equilibrium price and will sell their rights should there be any excess rations. However, the basic water requirement, 72.66 liters per capita per day as estimated above, cannot be traded. We use the *Walrasian auctioneer* to determine the equilibrium water price, which is determined at the market clearing condition. The simulated equilibrium price is 20.443 NT\$/M^3. This price is notably higher than the current highest level of block rates in Taipei.

The average statistics of water consumption, water expenditure and its change, and expenditure-income ratio per household after trading by quintile are shown in Table 3. In the columns of "Sorted by *I*", i.e., the households are sorted by disposable income quintile, the net expenditures from trading WR (cost from buying water rights – revenue from selling water rights) show that the poorest two household groups are the buyers of water rights and their water expenditures increase after trading. This outcome might mainly be due to the fact that the household sizes of poorer groups are smaller than those of the richer groups (see Table 1). Therefore fewer initial water rights are allocated to these households. From this

[18] There are 6,253 persons in the sample and 17.241=107,808/6253.

outcome, it seems that trading would worsen the income distribution. However, if we re-sort the quintile by disposable income per capita and water consumption per capita, respectively, the story changes. In the columns of “Sorted by PC *I*”, the net expenditures from trading WR for households with lower income per capita are negative. The poorer persons do gain from trade and the situation of income distribution is improved. The water share is around 20% for each quintile. Furthermore, in columns of “Sorted by PC WC”, households with lower water consumption per capita can earn more from selling water rights and households with higher water consumption per capita should pay more for buying water rights. This outcome is compatible with the user pays principle.

3.4 The simulated market price elasticity

One of the advantages of the agent-based model is that it can be used to simulate different scenarios but is based on the water-use behavior of households. In this subsection, we further discuss the price elasticity under the scenario of changing the total quantity of water supply.

Suppose that there are 41 different cases where total water supply varies and water rights allocated for individual persons vary correspondingly from 7.241 to 27.241 cubic meters with an increment of 0.5 cubic meters.[19] The *Walrasian auctioneer* is used to determine the equilibrium water prices under these various levels of water supply cases. The simulation results of the market equilibrium are graphically displayed in Figure 2.

The upper panel of Figure 2 shows the market-clearing price under different levels of total water supply. Since the equilibrium water prices are determined when water demand equals water supply, the curve in Figure 2 is in essence water demand curve. Furthermore, because the simulation has generated 41 data points, we then use these data to run a double-log regression. The estimates are presented as follows (t-ratio in parentheses):

$$\ln Q = \underset{(216.15)}{12.953} - \underset{(-24.649)}{0.438} \ln p_w + u \,, \quad \overline{R}^2 = 0.94 \,.$$

The coefficient of $\ln p_w$, -0.438, represents the market water demand elasticity, which is higher than that for households in absolute value. We would like to emphasize that the simulated demand represents market aggregate demand. Unlike the estimated demand curve in the previous subsection, the aggregate demand here can respond to the water price from the behavior of the individual households.

The curve in the lower panel of Figure 2 is presented using a logarithmic scale so that the slope can be defined as the elasticity of water demand. It is observed that, the lower the total water supply, the smaller the water demand elasticity. When the total water supply approaches the minimum water requirement, the absolute value of elasticity will approach

[19] As mentioned above, each person is allocated 17.241 cubic meters of water rights bimonthly. We take a range of 20 cubic meters around this number to specify the simulation scenario. The case number of 41 is got by the calculation: 41= (27.241-7.241)/0.5+1. Correspondingly, the total quantity of water supply varies from 45,278 to 170,338 cubic meters.

zero. On the other hand, if abundant water is supplied, its elasticity will asymptotically go to -1. A rough estimate of the price elasticity for the status quo total water supply is -0.615.[20]

4. Conclusion

Because some of the goals of residential water use are mutually conflicting, existing pure price systems are, in practice, systematically underpriced. This paper supplements the existing price system with a cap-and-trade measure to reconcile these problems. One of the price-cum-trade incentive system's (PTS's) advantages is that it forces everyone to face the correct price signal. Under the existing pure price systems, the interests of all water users (regardless of whether they are rich or poor) are the same—they do not prefer a higher water price. Under the PTS, however, these common interests are broken. Because the poor could save water to sell it at a higher price and earn money, they do not need to protest against a higher price, while major water users are now forced to face higher prices.

The cap on residential water use can be used in considering other values of water use, such as environmental and ecological values among others. The market then works by itself to reach the equilibrium. The government does not need to set the optimal price. Moreover, when people take active steps to save water, the government should educate people and publish information on how to save water.

[20] It is estimated by using three data points: the status quo ($\ln p_w$, $\ln Q$) and its two contiguous data points.

In this paper, using the agent-based PTS model, the trading of water rights is simulated. People with lower disposable income per capita and/or with lower water consumption per capita do earn from trade and equity is improved. In addition, the results of our simulated elasticity fall within the range suggested by empirical studies. Based on the behavior of the individual households, we have also explored the aggregate water demand responding to various water prices. The market demand elasticity is higher than that of household level and decreases as the total water supply is reduced.

Some transaction costs would occur because of the trades. Experiments based on true trading therefore deserve further research to help explore the PTS and reduce the transaction costs. Transaction costs might also be reduced by measures such as an effective brokerage system, a transparent and real-time information system, and separating the trading procedure into trading and implementation periods. It should be noted that trades might not be popular at the beginning. However, the price information provided by the trades is very important because it would induce people to use and save water with a more conscious attitude.

Finally, when the water market works well, some derivatives such as options and futures for water might be derived. These instruments could help reduce the uncertainty of water availability. Furthermore, the problems of stolen water and the overuse of ground water might become worse as water becomes more valuable. These topics, related with compliance and derivatives, should also be interesting for further study.

Appendix 1. Rate structure for tap water in Taipei (monthly per household)

	Block 1	Block 2	Block 3	Block 4	Block 5
Water consumption (M^3)	1-20	21-60	61-200	201-1000	1001+
Rate (NT$/ M^3)	5.0	5.2	5.7	6.5	7.6

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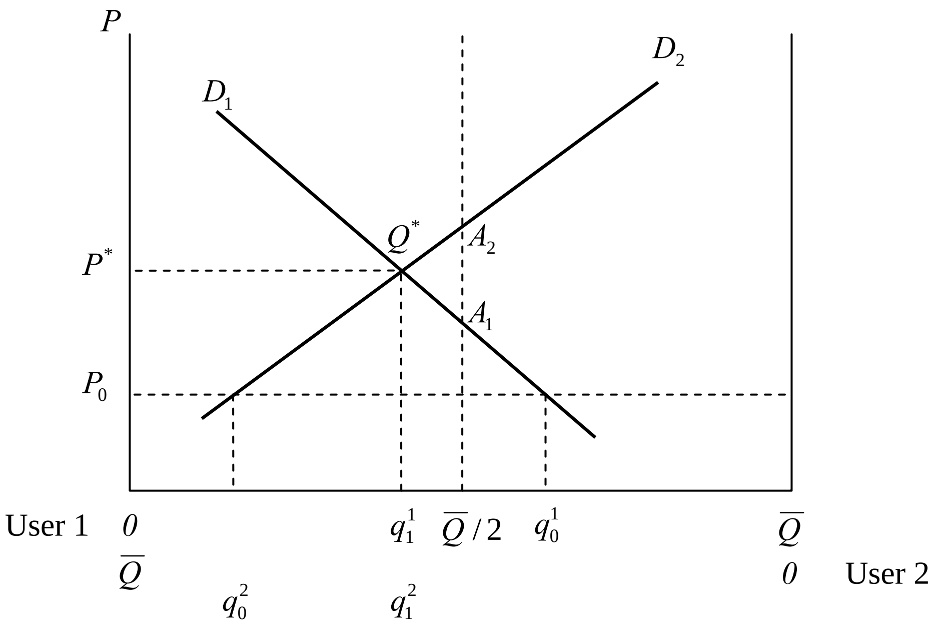
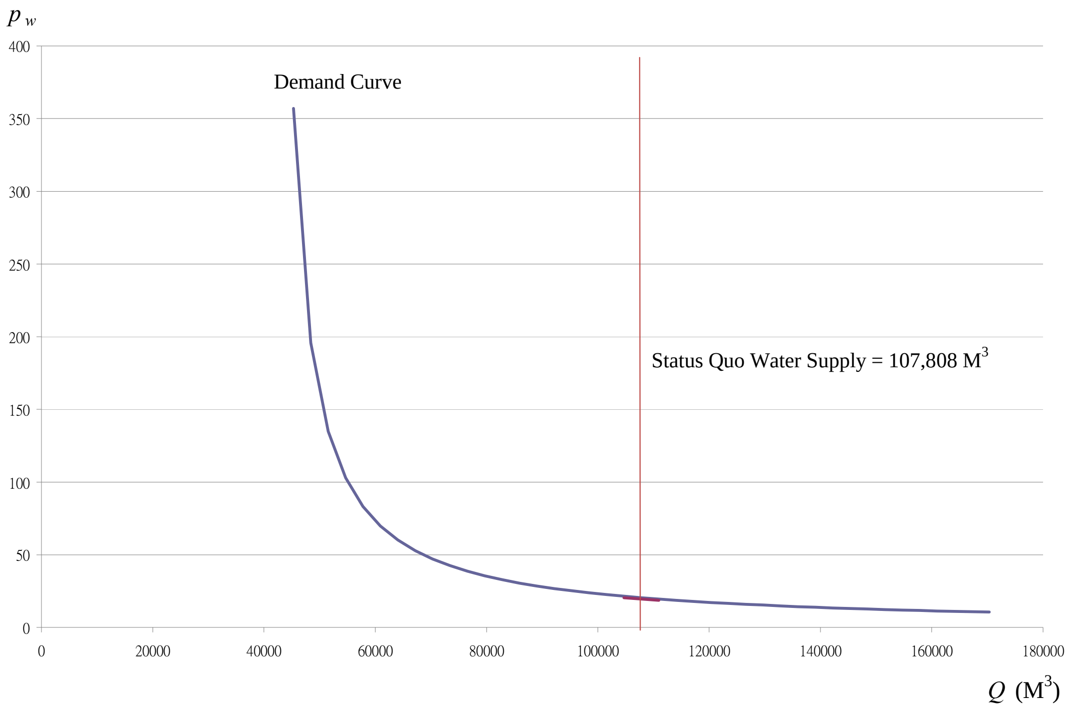


Figure 1. The equilibrium of the water market



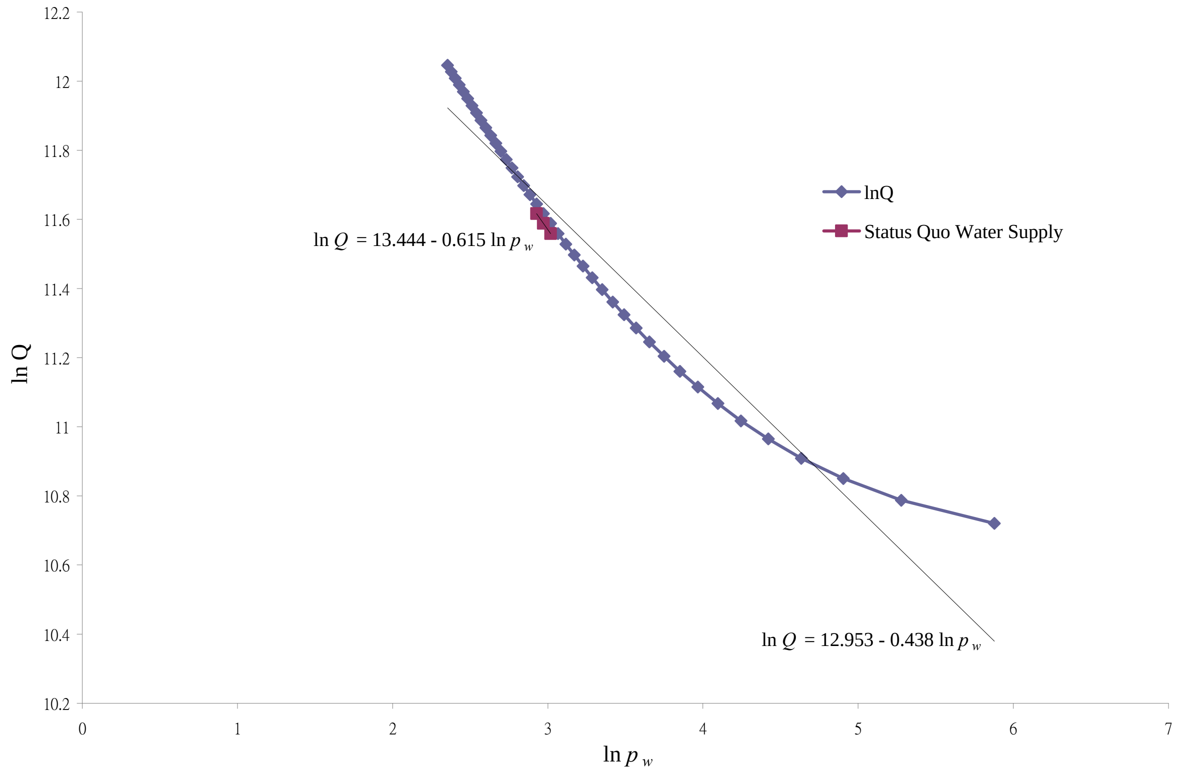


Figure 2. The water demand curves

Table 1. Bimonthly average statistics of disposable income, water expenditure, and water consumption per household

(by disposable income quintile)

	Lowest 20 percent	Fourth 20 percent	Third 20 percent	Second 20 percent	Highest 20 percent
Disposable income (NT$)	81,107	135,397	182,566	247,373	385,759
Water consumption (M^3) (share of total water consumption)	36.276 (13.36%)	51.596 (19.00%)	55.451 (20.42%)	62.117 (22.87%)	66.118 (24.35%)
Water expenditure (NT$)	500	656	695	763	804
Expenditure-Income ratio	0.62%	0.48%	0.38%	0.31%	0.21%
Household size (person)	1.95	2.88	3.29	3.66	3.97

Note: 1. There are 397 households in each quintile.

2. The exchange rate is 1 US$ = 32.167 NT$ in 2005. (Data source: Central Bank of the Republic of China)

Table 2. Descriptive statistics of variables

Variable	Description	Unit	Mean	SD	Median	Max.	Min.	Skew.
I	Disposable income	NT$	206440	119086	180554	1386616	11762	2.01
WE	Water expenditure	NT$	683.57	325.02	600	4000	150	1.99
α	Expenditure-Income ratio (= WE/I)	%	0.41	0.28	0.35	4.96	0.04	4.36
q_w	Water consumption	M^3	54.31	31.68	46.30	367.50	1.40	1.87
p_w	Average price (= WE/q_w)	NT$	13.76	3.92	12.96	107.14	10.88	9.72
N	Household size	person	3.15	1.32	3	9	1	0.28
H	House size	M^2	101.32	40.12	99.17	495.87	9.92	1.91
EDU	Education level of householder		6.18	1.97	6	10	1	-0.33

Note: The education level of householder is labeled as 1 for illiteracy, 2 for self study, 3 for primary school, 4 for junior high school, 5 for senior high school, 6 for vocational high school, 7 for college, 8 for university, 9 for master, and 10 for Ph.D., respectively.

Table 3. Changes in water expenditure after trading

	Lowest 20 percent			Fourth 20 percent			Third 20 percent			Second 20 percent			Highest 20 percent		
Average statistics per household	Sorted by *I*	Sorted by PC *I*	Sorted by PC WC	Sorted by *I*	Sorted by PC *I*	Sorted by PC WC	Sorted by *I*	Sorted by PC *I*	Sorted by PC WC	Sorted by *I*	Sorted by PC *I*	Sorted by PC WC	Sorted by *I*	Sorted by PC *I*	Sorted by PC WC
q_w (M^3) (water share)	38.51 (14%)	55.612 (20%)	43.198 (16%)	51.24 (19%)	53.790 (20%)	49.912 (18%)	55.50 (20%)	56.633 (21%)	53.969 (20%)	60.93 (22%)	54.940 (20%)	60.235 (22%)	65.38 (24%)	50.583 (19%)	64.244 (24%)
WE for initial WR$^{(1)}$	473	770	768	635	720	739	708	712	700	772	655	671	826	555	535
Net expenditure from trading WR$^{(2)}$	100	-151	-398	33	-86	-204	-27	-12	-42	-44	68	145	-62	181	499
Post-trading WE$^{(3)}$	573	619	370	668	634	535	681	700	658	728	723	816	764	736	1034
Status quo WE$^{(4)}$	500	685	422	656	666	566	695	713	667	763	701	803	804	653	961
ΔWE $^{(5)}$	+73	-66	-52	+12	-32	-31	-14	-13	-9	-35	+22	+13	-40	+83	+73
WE-Income ratio$^{(6)}$	0.71%	0.52%	0.18%	0.49%	0.39%	0.25%	0.37%	0.34%	0.31%	0.29%	0.30%	0.38%	0.20%	0.24%	0.56%

Note: 1. The abbreviations of WE, WR, Δ, PC, and WC represent water expenditure, water right, change, per capita, and water consumption, respectively.

2. In the first column, the item with superscript (3) = (1) + (2); (5) = (3) – (4); and (6) = (3) / *I*.