Urban Water and Wastewater Privatization in China

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Abstract

In 1949, the People’s Republic of China was founded. The founding of the People’s Republic of China also established China as a command economy, which is a system in which the State, not the market, decides what goods are to be produced, how much of each good is produced, and the prices at which the goods are sold. Since the founding of the PRC and for thirty years, the State was in charge of the investment, construction, and operation of public utilities, such as roads, electricity, telecommunications, water, and wastewater. These public utilities were run by State-Owned-Enterprises (SOE’s), which received financial support exclusively from the central government. In 1979, the Chinese economic system underwent a seismic change when the government introduced its policy of “Separation of Government and Enterprises.” Following the introduction of this policy, public utilities – although they remained as SOE’s – were handed down to local governments. The responsibility and the operation of these public utilities now belonged to local governments. This paper presents the reform experience of China’s urban water and wastewater sector, and proposes a theoretical model for deciding whether a mater project should be privatized under a BOT (Build-Operate-Transfer) concession. Using a set of cross section data on China’s major cities, a demand curve for water is estimated. From this market demand curve for a city and using the data on construction costs, operating, and maintenance costs as well as revenues for a water firm in Shenzhen, we calibrate the demand curve for water faced by this firm and its marginal cost. The calibrated model is then used to compute the social welfare obtained when the government chooses to privatize the water project under the form of a BOT (Build-Operate-Transfer) concession for a period of 20 years during which the private water firm is granted monopoly power over a water market and the social welfare obtained when the government chooses to carry out the water project itself. The analysis does not favor privatization.

CONTENT

1. INTRODUCTION

After their victory in the civil war against the Nationalists of Chiang Kai-shek, the Chinese Communists declared the founding of the People's Republic of China (PRC) on October 1, 1949. The founding of the PRC also established China as a command economy, which is a system in which the State, not the market, decides what goods are to be produced, how much of each good is produced, and the prices at which the goods are sold. Since the founding of the PRC and for thirty years, the State was in charge of the investment, construction, and operation of public utilities, such as roads, electricity, telecommunications, water, and wastewater. These public utilities were run by State-Owned-Enterprises (SOE's), which received financial support exclusively from the central government. In 1979, the Chinese economic system underwent a seismic change when the government introduced its policy of "*Separation of Government and Enterprises*." Following the introduction of this policy, public utilities – although they remained as SOE's – were handed down to local governments. The responsibility and the operation of these public utilities now belonged to local governments. Furthermore, these SOE's were allowed to operate as independent firms, assuming full responsibility for their own profits and losses. The reform experience of the urban water and wastewater sector was carried out against this background of market liberalization. The subject of this paper is the privatization of China's urban water and wastewater.

The literature on China's urban water and wastewater privatization is sparse and consists mainly of case studies, but few empirical works. The case studies are mainly descriptive in which detailed and complex organization structures are provided. They are also full of acronyms and government decrees that are incomprehensible to a foreign researcher. These studies judge whether a water project is a success or a failure on the basis of several indicators: the percentage of the population covered, water quality, service quality, water tariff, water leakage, the percentage of the budget spent on water by the poor, etc. Lacking in these studies are the data on the costs of water provision without which a discussion on water tariff is incomprehensible. Even an econometric study concludes that the water reform in China is a success without using cost or price data in the estimation of various indicators used in case studies. A solid economic analysis is yet to emerge. The main objective of this paper is to fill part of this lacuna by formalizing a theoretical model of water privatization under the form of a BOT (Build-Operate-Transfer) concession that lasts 20-30 years. Using a set of cross section data for a number of China's major cities, we estimate the market demand for an urban center. Using this estimated market demand curve for a city and data on construction costs, operating costs, maintenance costs, and revenues over a period of six years, we calibrate the demand curve faced by a water firm – among several water firms in the city of Shenzhen. Ideally, we prefer to estimate the demand curve and the marginal cost of this firm using time series data from this firm. However, such data are hard to come by, perhaps because the Chinese government does not wish to reveal them either for reason of incompetence or for corruption. The calibrated model for the Shenzhen firm is then used to compute the present value of the stream of social welfare obtained under the case the government chooses to carry out the water project itself and the present value of the stream of social welfare under a BOT concession in which the private firm is granted monopoly power for 20 years and are free to set the water tariff to maximize monopoly profits. The results of our numerical exercise indicate that discounted social welfare is higher under the no privatization choice than under the privatization choice. The economic logic is simple: the water tariff during the duration of the BOT concession – due to monopoly power – is much higher under privatization than under no privatization. Thus, unless the government can impose a limit on how high the private water firm can set the water tariff, it is not socially optimal to privatize the water project.

The paper is organized as follows. In Section 2, a brief account of the development of China's urban water and wastewater sector is presented. Section 3 presents the conventional arguments for infrastructure privatization. Section 4 presents an abridged account of the international experience in the privatization of public water utilities. An explanation for the failure of the international experiment is provided in Section 5. The sparse literature on China's experience on her reform of the urban water sector is discussed and evaluated in Section 6. Section 7 contains our economic model of a BOT concession. The model presented in Section 7 is calibrated in Section 8, using data on costs and revenues of a water plant in Shenzhen. Section 9 contains some concluding remarks. Sections 1 through 6 provide the background for Sections 7 and 8, which constitute the centerpiece of the paper.

2. THE DEVELOPMENT OF URBAN WATER AND WASTE WATER INFRASTRUCURE IN CHINA

At the time reform began, China's urban water and wastewater experienced numerous problems: water shortage, water pollution, lack of funds for investment in infrastructure, poor management, low efficiency, and low coverage.

In 2016, the population of China stands at 1.4 billion. China's extraordinary industrialization induces a rapid urbanization of its population. By1950 in China, 13 % of the population lived in cities. By 2010, the proportion of the population who lived in urban centers had risen to 45%. It is projected that by 2030, 60% of China's population will be living in cities. Twenty-five of the world's largest cities are in China. Although China accounts for 25% of the world population, she has only 6% of its fresh water supply.[1] Together, overpopulation, rapid industrialization, and accelerating urbanization have exerted enormous pressure on her water resources to meet the needs of her large cities. In its rush to become the manufacturing center of the world, China has polluted her lakes and rivers. Roughly one third of industrial wastewater and over 90% of household sewage are released into rivers and lakes without being treated.[2] Half of China's urban drinking water fails to meet standards.[3] More than half of China's ground water is polluted.[4] A recent government

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[1] Barlow, Maude and Tony Clarke (2002): Blue Gold, New York: The New Press.

[2] Water Pollution in China|Facts, factsanddetails.com.

[3] https://www.**china**dialogue.net/.../6074-Half-of-**China**-s-**urban**-drinking-**water**-fails-to...

study found that 90% groundwater of China's cities is contaminated, most of it severely. [Source: Jonathan Kaiman, The Guardian, February 21, 2013]. Water pollution thus aggravated its water shortage problem: the shortage of quality drinking water.

According to Zhong et al. (2008),[5] the reform of China's urban water sector can be divided into three stages.

The first stage, which lasted from the early 1980's until the mid 1990's, marked the beginning of China's reform in the urban water and wastewater sector. During this period, accelerating urbanization and rapid industrialization combined to generate increasing demand for water and wastewater infrastructures. The water supply and wastewater plants still received subsidies from the government. Local governments, which owned and operated these plants, also made investments in new infrastructures with funds borrowed through intergovernmental loans or loans provided by international lending institutions, with the backing of the central government. The reform also allowed household water tariff to be set at a level where water companies could recover costs and make a small profit.[6] The water tariff was raised numerous times during this period.

The second stage, which lasted from the mid 1990's to 2002, witnessed the continued rapid urbanization and industrialization of China with the ensuing degradation of the

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[4] Jonathan Kaiman (Wednesday 23 April 2014), The Guardian, https://www.theguardian.com/environment/2014/april/23/china-half-groundwater-polluted.

[5] Lijin Zhong et al. (2008): "Public-Private Partnership in China's Urban Water Sector," Environmental Management 41: 863-877.

[6] Yun Ge (2008): Rethinking China's Urban Water Privatization, Xinjiang Conservation Fund.

environment. The number of wastewater treatment plants was insufficient to treat the used water, and water pollution became a serious problem. To solve the water pollution problem and to ease the lack of funds for investment in infrastructures, the central government introduced the policy of Build-Operate-Transfer (BOT),[7] which provided the legal basis for private sector involvement and foreign capital investments in China's infrastructures.[8] As expected, transnational water corporations (TNC) began to enter China's water sector, bringing with them the advanced technology in wastewater treatment and more efficient management techniques. In 1992, Sino-French Water (a joint venture between Suez Group and Hong Kong based NWS holding Limited) built and managed the Tan Chau water project in the city of Zhongshan. After that, one witnessed the arrival and participation of TNC's, such as Suez, Veolia, and Thames Water in China's urban water market. Meanwhile, household water tariffs continued to rise during this period.

The third stage, which began in 2003 and is still evolving at the present time, is a continuation of the second stage, with the central government showing its determination and steadfast commitment to a full-scale privatization of the urban water and wastewater sector. Local governments are encouraged to open their doors to domestic and foreign capital. The central government also introduced competition in the sectors that were formerly monopolized by the SOE's to raise the efficiency of these sectors. At the present time,

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[7] Under a BOT arrangement, the company pays the full cost of constructing the reservoir or treatment plant, and is contracted to operate the plant for a defined period (usually between 15-30 years), after which the facility is transferred to the public sector.

[8] Lijin Zhong et al. (2008), op cit.

domestic and foreign water firms actively participate in China's urban water supply and wastewater treatment sector. Among the foreign water firms, one might mention TNC's, such as Veolia and Suez. Among domestic water firms, one observes (i) investment groups, such as the Beijing Capital Group and Tianjin Capital Environmental Protection Co. Ltd. (ii) liberalized water companies, such as Shenzhen Water Group and Beijing Sewerage Group); and (iii) environmental engineering corporations, such as Beijing Sound Group and Tsinghua Tongfang Water Engineering Corporation). As of July 2005, 152 water supply projects (17% of national production capacity) and 200 wastewater treatment projects (67% of the national wastewater treatment capacity) involved participation from the private sector.[9] The fixed rate of return offered by the policy during the early years of the reform has been modified. Now private investors have to bear some of the risks.

3. THE RATIONALE FOR INFRASTRUCTURE PRIVATIZATION

Over the last two decades, academics and policy makers debated on the merits and disadvantages of infrastructure privatization.[10] The support for infrastructure privatization manifested itself during most of the 1990's when a worldwide wave of privatization swept the water utilities. The enthusiasm has now disappeared in high-profile countries, such as

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[9] Lijin Zhong et al., op cit.

[10] See Antonia Estache and Caroline Philippe (2012): "The Impact of Private Participation in Infrastructure in Developing Countries: Taking Stock of about 20 Years of Experience," ECARES Working Paper 2012-043.

Argentina, Bolivia, Mali, Senegal, and Venezuela. However, the wave of privatization is still going strong in China, India, Eastern Europe, Central America, and many countries in Africa. The economic argument for infrastructure privatization is based on two hypotheses: the fiscal hypothesis and the efficiency hypothesis.[11]

The government of a country pursues multiple objectives, such as providing public goods, regulating industries with high degrees of concentration, and controlling externalities – all under a single budget constraint. There is an opportunity cost when public funds are used for investment in one sector than in another sector. The opportunity cost is the benefit forgone in the alternative investment, and this opportunity cost is the Lagrange multiplier associated with the government budget constraint in the welfare maximization problem. Over the last 25 years, developing countries have experienced problematic budgetary conditions, and the fiscal hypothesis suggests that the government can use the proceeds obtained from privatization to relax its budget constraint. Privatization also means possible termination of recurrent subsidies to SOE's for their chronic losses. International financial institutions, such as the World Bank, the International Monetary Fund, and the Asian Development Bank, have given economic assistances to privatization.

The efficiency hypothesis has its underpinnings from the public choice theories of government behavior. According to this aspect, the poor performance of public water utilities can be attributed to four elementary incentive issues. First, water is essential for life, and is

[11] Braadbart, O. (2001): Privatizing Water: The Jakarta Concession and the Limits of Contract. Paper presented at the Jubilee Workshop on "Water as a Life Giving and Deadly Force", Leiden, The Netherlands, 14–16 June 2001.

considered as a right – not an ordinary good – by a vast majority of people. Thus, governments in developing countries often yield to public pressure, and maintain water tariffs below cost. The cost of water provision – although hidden – must ultimately be borne by the collective, and the subsidies to public water utilities distort the allocation of resources. The low water tariff, as often argued by the government, encourages the wasteful use of this precious resource. Second, public water utilities, due to the subsidies they receive, have a "*soft budget constraint,"* and are thus insulated from market pressure to maintain solvency. Third, public water utilities suffer from agency problems because the owner is also the regulator. Fourth, because bankruptcy threat does not apply to public water utilities, these SOE's have no incentive to innovate.

The confluence of poor performance of public utilities, tight budget constraints, pressure from international lending institutions, and the argument buttressed by public choice theories encouraged many developing countries to privatize the provision of goods previously supplied by public utilities.

4. WATER UTILITIES PRIVATIZATION: THE INTERNATIONAL EXPERIENCE

Araral (2009) examined the evidence of the international wave of water utilities privatization and concluded that the experience was a failure.[12] The conclusion reached by Araral derived from the work of Hall and Lobina (2006)[13] on the fiscal hypothesis and the empirical studies of Estache et al. (2005),[14] Estache and Rossi (2002),[15] Hall and Lobina (2006), Kirpatrick et al. (2004),[16] Motta and Moreira (2004),[17] and Perard (2007)[18] on the efficiency hypothesis.

After a comprehensive and in depth review of the evidence on the fiscal hypothesis, Hall and Lobina found no support for the proposition that privatization will relieve the financial burden of government investment. Firstly, most private contracts, especially lease and management contracts, involved no investment by the private company to extend coverage to poor unconnected households. Concession contracts did involve investment to lengthen the

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[12] Eduardo Araral (2009): "The Failure of Water Utilities Privatization: Synthesis of Evidence, Analysis and Implications," Policy and Society 27, 221-228.

[13] D. Hall, E. Lobina (2006): "Pipe Dreams: The Failure of the Private Sector to Invest in Water Services in Developing Countries, Public Services International, University of Greenwich, London.

[14] Estache et al. (2005): *Infrastructure Performance and Reform in Developing and Transition Economies: Evidence form a Survey of Production Measures*, World Bank Policy Research Working Paper 3514.

[15] Estache E., and M. Rossi (2002): "How Different is the Efficiency of Public and Private Water Companies in Asia," *The World Bank Economic Review* 1(1).

[16] Kirpatrick, C. et al. (2004): *State versus Private Provision of Water Services in Africa: An Empirical Analysis,* University of Manchester Centre on Regulation and Competition, Working Paper Series, Paper #70.

[17] Motta, R. S. and A. R. Moreira (2004): Efficiency and Regulation in the Sanitation Sector in Brazil, IPEA Discussion Paper No. 11059.

[18] Perard E. (2007): *Water Supply: Public or Private? An Approach Based on Cost of Funds, Transaction Costs, Efficiency, and Political Costs*, Paper presented at the Conference on the Role of the State in Service Delivery, October 28-29, 2007, Lee Kuan Yew School of Public Policy, Singapore.

distribution network; however, the initial commitments when the contracts were signed were invariably revised, abandoned, or missed because the private companies became distressed. Second, in most privatization contracts, the investment made to connect poor households required public finance, guarantees from the government, or loans from government-owned development banks. Third, private companies did not bring in their own equities, but relied heavily on the same sources of finance which were available to the government. Fourth, the contributions of TNC's in water investments were negligible. This fact reflected the preferences of investors to put their funds in middle-income, not low-income, countries.

As for the efficiency hypothesis, recent empirical studies consistently and repeatedly showed that there is no systematic difference between the performance of SOE's and private companies based on efficiency or other performance measures. Willner and Parker (2002) observed that in some cases, SOE's were more efficient; in other case, private companies were more efficient; in other cases, there was no difference in performance between SOE's and private companies. Perard (2007), in a comprehensive review of 48 case studies and 22 econometric tests on the subject comparing the efficiency of public and private water utilities, also finds mixed results. It seems that ownership alone does not matter much as far as efficiency is concerned. In the endogenous growth theory, human capital plays a fundamental role in generating innovations, which are the source of economic growth. Perhaps, the ambiguous results from the empirical studies could be alleviated if human capital is included as another explanatory variable in the econometric model.

5. THE FAILURE OF WATER UTILITIES PRIVATIZATION: AN EXPLANATION

Shirley (2006) attributed the failure of water utilities privatization to the disregard by the conventional wisdom of the special characteristics of water.[19] According to the conventional view, advocated by most economists and policy makers, water is treated as a private good and its demand is presumed to be responsive to price, so that water should be priced at a level that covers costs – including capital investment costs – and the externalities it generates. However, the intrinsic characteristics of water is that it is an essential good, and life is not possible without a sufficient supply of good quality paper. As an essential good, water is considered by most individuals to be a right that even the poorest among us should have access to. According to this view, water should be a free good, or if it is priced, the price should be set low enough so that it is accessible to every one.[20] Because water is essential to life, its politics is intense, and resistance to tariff reform is ferocious. Furthermore, because water is local in supply, local politicians often succumb to populist pressure and renege on the contracts they sign with the private firms in the privatization process. Another characteristic of water is that investors lack information about the quality of the infrastructure because it is

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[19] Mary M. Shirley (2006): "Urban Water Reform: What We Know, What We Need to Know," Paper Presented for the Annual Meeting of the International Society for New Institutional Economics (ISNIE) in Boulder, Colorado, September 21-24, 2006.

[20] See, for example, Global Monitor (March 2009): Working Paper on The Reform of the Urban Water Supply in Southern China --- Water Privatization in China,

buried underground, and thus difficult to assess ex-ante. The information is only revealed during physical rehabilitation after the contract has been signed and the concessionaires realize that they have underestimated the costs involved in operating the system. The information asymmetry – the SOE's know the quality of the infrastructure, but the private firm does not – makes the design of a satisfactory contract difficult. The information asymmetry could explain partly why most water concessions were renegotiated only a short time after the signing of the contract. Another characteristics of water is that it is "*dull*", to use the terminology of Shirley, and that means the scope of innovation and a fortiori the dynamic gains are low. The low dynamic gains coupled with the credibility of the government to honor its commitment on tariff reform discourage investors from sinking their capital in water and wastewater utilities.

6. INFRASTRUCTURE AND URBAN WATER PRIVATIZATION: THE CHINESE EXPERIENCE

The existing literature on the privatization of China's urban water and wastewater utilities consists of two types of analysis: case studies and empirical analyses that compare a set of performance indicators across firms or counties before and after the reform. In the case of China's water and wastewater sector, little empirical work has been done to learn how public private partnership (PPP) affects the performance of this sector. Case studies, which are few in number, mostly dwell on the evolution, the institutional reform, and the tariff reform of this sector. This section presents an evaluation by Chinese researchers of the performance of the PPP approach to the privatization of water and wastewater services in China, first with the help of an econometric study, and then three case studies.

6.1. An Econometric Analysis of PPP in China's Urban Water and Wastewater Sector

In an econometric analysis of China's urban water and wastewater privatization, Wand et al. (2011),[21] assembled a panel data set of the water supply sector in 35 major cities (direct-controlled municipalities, provincial capitals, and cities specifically designated by the state plan) for the period 1998-2008. Using this dataset, these researchers examine the impact of PPP on the performance of China's urban water and wastewater sector.

According to Wand et al., the participation of the private sector in China's urban water and wastewater generated considerable capital inflows into this sector from international, private, and other non-state-owned sources. By the end of 2008, the private sector served about 20% of the market. During the period 1998- 2008, the performance of China's water supply significantly improved. To begin with, the average production capacity – an important indicator of urban water supply development – in the 35 main cities increased about 1.6 times of the level in 1998. The number for the eastern cities was 2.5, while the central and western cities showed a modest increase of only 19.7%. Second, in the 35 main cities, the coverage rate reached 96.5% by the end of 2008. As for the central and western cities, the coverage rate

[21] Hongwei Wang, Wenqing Wu, and Shilin Zheng (2011): "An Econometric Analysis of Private Sector Participation in China's Urban Water Supply," Utilities Policy 19 (2011) 134-141.

had risen by 17.7%, reducing the gap between these cities and the developed eastern cities. Third, construction of water supply in fixed assets investment also shows a large improvement in this period. The total investment in the urban water supply sector has increased by 36.7%. Lastly, the investment in infrastructure in the eastern cities rose by 47.9% between 1998 and 2008, while the less developed central and western cities showed a modest rise in infrastructure investment of 17.4%.

Although the performance of China's urban water and wastewater showed great improvement from 1998 to 2008, the Chinese economy also grew rapidly in this same period, and thus it is not clear whether the improvement in China's urban water and wastewater sector was driven by privatization or by the phenomenal growth of China's economy. To obtain a definite answer to this question a systematic empirical analysis is needed, and this is the objective of Wang et al.

In the econometric model they formulate, private firms are disaggregated into domestic and foreign firms. The econometric model formulated by Wand et al. is intended to test the impact of private sector participation on the performance of China's urban water and wastewater sector, considering to the characteristics of the reform carried out in this sector. In the regression equation, international private companies and domestic private companies are differentiated, and how each of them affects the sector. Among the control variables are GDP per capita, population density, and the urbanization of China. The dependent variables are production capacity, coverage rate, and investments in fixed assets. Fundamental economic variables, such as water tariff and marginal costs are notably absent from the econometric model. The reason, these researchers explain, is because they are hard to find.[22]

The data set used to estimate the regression equations includes industry and macro-economic development data for China's 30 provincial capitals and direct-controlled municipalities as well as five cities specifically designated in the state plan. The data on urban water supply industry come from "China Urban Construction Statistics Yearbook", 1998-2008. The data on urban macro-economic development are from Statistical Yearbook of each city during the period 1998-2008. The main findings provided by the regression results are as follows.

First, private participation in China's water and wastewater sector significantly raises the production capacity and the coverage rate of this sector. More specifically, private sector participation raises the production capacity about 11.8% – 14.9%, and increases the coverage rate by 4% – 5.2%. The implication of these results is that expanding the participation of the private companies in China's water and wastewater sector can improve the sector's performance, validating the efficiency hypothesis.

Second, private participation has a positive, but modest effect on the infrastructure investment in China's water and wastewater sector. In some cases, the impact is negative. A plausible explanation for the anemic investment in fixed assets is the limited property rights that are granted by the government to private investors, especially to foreign investors. The limited property rights together with the uncertain regulation environment are not conducive

[22] Perhaps, because Chinese authorities do not wish to reveal these data in their efforts to cover up incompetence or corruption.

to long-term, stable, and sustainable private investments.

Third, the growth in per capita income has a positive impact on coverage, but not production and operation capacity. On the other hand, population density and urbanization have a momentous negative impact on production and operation capacity, but no significant impact on coverage.

Fourth, foreign investments have a positive influence on the production capacity of China's water and wastewater sector. The participation of TNC's raises the production capacity by about 10.3% – 12.9% and the water coverage rate by 4.2% – 6.5%. However, the participation of domestic firms has only small effect on the performance of the water and wastewater sector.

6.2. Three Case Studies

The three case studies presented in this sub-section are the results of the fieldwork carried out by Zhong et al. (2008).[23]

6.2.1. Joint Venture: Maanshan Water Supply

Maanshan City is an industrial city of 1686 square kilometers and a population of 1.24 million (2004), and 46.8% of its population lives in urban areas. According to the 2004 statistics of the Ministry of Construction, 88.7% of the urban population has access to the water supply. Maanshan has an abundant supply of water. The city is situated on the south

[23] Lijin Zhong et al. (2008): "Public-Private Partnership in China's Urban Water Sector," Environmental Management 41: 863-877.

bank of the Yangtze River, and the annual rainfall is 1062-1092 mm. The Maanshan Construction Commission (MASCC) is the main authority for water supply and wastewater treatment in Maanshan City.

In 2002, following the call of the Central Government and the Anhui Provincial Government, Maanshan started a liberalization program in water and other public utilities. The objective of the reform is to transform the old Maanshan Water Supply Company (MASWSC) into a modern institution. MASWSC was established in 1958 as an SOE, with total assets of 4.37 million RMB,[24] or 0.528 million US dollars at the exchange rate of $1USD = 8.277RMB$. After negotiating with several private companies, MASCC started a joint venture – as a first trial – with Bejing Capital Group (BCG) for one water supply plant (WTP), with BCG owning 60% of the shares. This joint WTP sold purified water to MASWSC, and performed considerably better than the other WTP's run by MASWSC alone. In 2004, MASCC extended the joint venture with BCG to all WTP's of Maanshan City, with BCG owning 60% of the shares, bringing in 90 million RMB in revenues. The new joint venture company, called MAS-BCWLC, was awarded a 30-year concession. BCG (the private company) and MASWSC (public sector) share responsibility in investment, operation and maintenance of the WTP's (excluding the pipe networks) and service obligations. MAS-BCWLC manages the existing pipe network by signing a lease contract with MASWSC, which remains the owner of the assets and is responsible for its debts. MAS-BCWLC was asked to invest in new pipes in new development areas and non-piped

[24] RMB is the abbreviated symbol for the renminbi, the official currency of the People's Republic of China.

neighborhoods. The joint venture company was also required to fulfill some social obligations specified by the government. The government retains the power to control the water price. To ensure a supply of high-quality water and service, MASCC regulates the performance of MAS-BCWLC. The government stopped subsidizing the WTP's after the involvement of BCG, and the joint venture even turned over about 18.7 million RMB.

The improved quality of water provision satisfied consumers and made it possible for the government to raise the water tariff from 0.83 to 1.08RMB/m^3. For a household, water use accounts for around 1.16% of income. The participation of BCG injected additional capital to develop Maanshan's water and wastewater sector. It changed the institutional structure, improved the delivery of good-quality water and services. It also reduced government intervention in this sector. The government benefited from tax revenues paid by the joint venture firm, dividends, while transferring part of the financing, building, and operational risks to the private operator.

6.2.2. Concession Contract: Macau Water Supply

Macau is one of the two Special Administration Regions[25] of China, a former colony of Portugal until 1999. It is a small area of 28 km^2 on the southern coast of China, consisting of a peninsula and the islands of Taipa and Coloane. In 2006, Macau had a population of 508, 000.

[25] Hong Kong is the other Special Administration Region.

Macau Water Company Ltd. (MWC) was established in 1932 as a full fledge private company. Three years later, MWC was taken over by British Lightning Company for 10 years, and then since 1946 by the head of Macau Economic Department and private investors. Due to lack of capital and advanced technologies, MWC had a poor record of poor quality water provision and interrupted service during the 1970's. In 1985, the Macau Government, profiting from the French experience in water management, awarded a 25-year concession contract to a consortium made up of two private companies – NWS Holding Limits (Hong Kong) and Suez Environment (France). The Macau Government remained the owner of the existing assets (plants and pipe network). The new concessionaire, called Macau Water Supply Ltd. (MWSL) is responsible for the operation, maintenance of these assets as well as for new investments and service obligations under the supervision of the Macau Government. As a partner in the concession, Suez brought in advanced water knowledge and technology. At the end of the 25-year concession, MWSL had fulfilled most of the terms of the initial contract. MWSL had considerably improved water quality, water provision, and access while maintaining a stable (adjusted for inflation) water tariff. On the equity issue, MWSL managed to reduce the water bills for low-income households, disabled and other vulnerable groups. It had also supplied water at discounted prices and paid taxes to the Macau Government. In both Maanshan and Macau, there were no government subsidies, and the water tariff was the only source of revenues for water companies. In the case of Macau, the government owned the pre-concession infrastructure, and MWSL did not have to incur the heavy cost of capital investment. Thus, spikes in water tariff, which is often the main reason for public resistance to privatization, were not needed for the solvency of the new water company. The water tariff was more than sufficient to cover the costs of operations and maintenance incurred by MWSL.

6.2.3. Greenfield Contract: Shanghai Wastewater

The Greenfield contract (BOT, TOT) is the dominant form of private participation in the wastewater sector. Shanghai Zhuyuan N0. 1 WWTP is one of the largest WWTP in China. It has a treatment capacity of 1.7 million m^3 per day and an advanced primary treatment that serves 23.5 million inhabitants in an area of 107 km^2. This WWTP has the lowest service price in China: 0.22RMB/m^3.

In 2002, the Youlian consortium[26] won the open tender for Shanghai Zhuyuan No. 1 WWTP by bidding the lowest cost. A Project Company (Shanghai Zhuyuan Youlian No.1 Wastewater Treatment Ltd. Co) was formed and awarded a 20-year concession by Shanghai Water Authority. The Project Company signed a service management contract with Shanghai Sewage Company, an SOE. According to the agreement between the Shanghai Water Authority and the Project Company, the former should limit its intervention to the issues of safeguarding public health and safety. All conditions on water service quality are defined in the contract between the Project Company and the Shanghai Sewage Company. The Project Company is also required to install and pay for an online monitoring system, which is monitored by an independent third party. According to local authorities, Shanghai Zhuyuan

[26] The Youlian consortium is made up of Youlian Development Company (45% shares), Huajin Information Investment Ltd. Company (40% shares), and Shanghai Urban Construction Group (15% shares).

WWTP has fulfilled up to now all the obligations, including water quality standard, specified in the initial contract.

In the case of Shanghai Zhuyuan Greenfield project, the government transferred its traditional responsibilities of investment, construction, operation, and maintenance – for the duration of the contract – to the private company. The participation of the private company was also facilitated by a subsidy of 20 million USD in the fixed infrastructure of the project and preferential land use policies. In contrast with the joint venture in Maanshan and the concession in Macau in which water tariff is the only source of revenues for the private companies, the private company involved in the Greenfield project is paid a service price negotiated between the government and the private operator. Because the contract has a long duration, it is still too early to assess the success of failure of the Greenfield project.

7. A BOT (BUILD-OPERATE-TRANSFER) MODEL OF URBAN WATER AND WASTEWATER PRIVATIZATION

For more than 20 years, academics and policy makers have been debating the merits of infrastructure privatization. Much of the debate is ideological, and is not based on formal economic models that delineate the social costs and social benefits of a privatization project. In the debate, the following criteria are most relied on to assess the success or failure of a privatization project.

(i) Fiscal/financial viability: Does the public sector meet its fiscal objectives – which might include subsidies to the private firm – and is the operation financially sustainable for the private firm?

(ii) Efficiency: Is the operation being carried out at lower cost? Do prices reflect costs, not monopoly power?

(iii) Governance: Does the project have institutional support? Is it transparent? How does it account for mismanagement and corruption?

(iv) Equity: Are the poor better- or worse-off with the public private partnership?

This section presents a theoretical model that attempts to answer the question on whether an infrastructure should be privatized. The model is formalized from the perspective of the fiscal hypothesis under the form of a BOT contract.

Consider a city in which the population, say the number of households, in period t is denoted by $N_t, t = 0,1, ...$ Through immigration from the countryside, the number of households in the city is expected to grow with time. Let $q = a - bp$ denote the demand curve for water by a household. Here q is the volume of water demanded at price p and $a > 0, b > 0$ are two parameters. Summing the individual household demand curves, we obtain the following market demand curve for water in period t:

(1) $$Q_t = N_t(a - bp),$$

where Q_t is market demand at price p. The market demand curve for water in period t can also be expressed under the following inverse form:

(2) $p_t = \frac{a}{b} - \frac{Q_t}{bN_t}$.

To serve the market, a water treatment plant and its associated infrastructure must be built in period 0 after which the plant can be operated in period 1, 2,… The construction of the water treatment plant involves a fixed investment of K in period 0, and once the plant has been built, it can be operated at a constant unit cost of $c > 0$ for $\overline{T}$ periods, where $\overline{T}$ is a positive integer that represents the useful lifetime of the plant. The government can either build and then operate the water treatment plant itself or privatize the project through a BOT contract that lasts T periods, with $T < \overline{T}$.

7.1. The Case of No Privatization

If the government does not privatize the water project, then it will pay $(1 + \lambda)K$ in period 0 to build the water treatment plant. Here λ is the shadow price (opportunity cost) of public funds. Now the government pursues multiple objectives, such as production of public goods, regulating non-competitive sectors of the economy, and controlling externalities, under a single budget constraint. Withdrawing one dollar from one sector to invest in the water sector raises welfare in the latter sector at the opportunity cost of $1 + \lambda$, which includes the loss of one dollar in the sector from which the funds are diverted plus the extra loss in social welfare λ. In industrialized countries, λ is estimated to be around 0.3, which is taken as the deadweight loss associated with imperfect income taxation.[27] In developing countries, low

[27] Snower, A. and R. Warren (1996): "The Marginal Welfare Cost of Public Funds: Theory and Estimates," *Journal of Public Economics* 61(2): 289-305.

incomes coupled with difficulties in implementing effective taxation impose an unbearable constraint on the government budget. The World Bank (1998)[28] suggested a value of $\lambda = 0.9$ as a benchmark for developing countries. In heavily indebted countries, the opportunity cost of public funds might be much higher than 0.9.

Given that the marginal cost of water provision is c in each period $= 1, \ldots, \overline{T}$, the socially optimal volume of water produced in each period is at the level where marginal cost is equal to the market price. More precisely, the volume of water provided by the government in period t is given by

(3) $$Q_t^* = bN_t\left(\frac{a}{b} - c\right), \qquad \left(t = 1, \ldots, \overline{T}\right).$$

The social welfare, namely the consumer surplus, in period t is then given by

(4) $$\omega_t^* = \int_0^{Q_t^*}\left(\frac{a}{b} - \frac{Q}{bN_t}\right)dQ - cQ_t^* \qquad \left(t = 1, \ldots, \overline{T}\right).$$

The present value of the stream of social welfare obtained under the case where the government chooses not to privatize the water project is then given by

(5) $$\Omega^* = -(1 + \lambda)K + \sum_{t=1}^{\overline{T}} \delta^t\, \omega_t^*.$$

Using the symbolic computational capability, we have managed to obtain a closed-form expression for Ω^* in terms of the parameters of the model. However, because this expression is long and complicated, we have decided not to report it here.

28 World Bank (1998): *World Development Indicators*, 1998. Washington D.C.: World Bank.

7.2. Privatization with BOT Contract

Suppose that under the BOT contract the private firm is granted monopoly power over the market in question for T periods. That is, the private firm spends K to construct the water treatment plant in period 0; operates the plant in periods 1, 2,…, T as a monopoly in the water market in question; and then ceases all activities in this market by transferring the water treatment plant to the government at the end of period T.

During each period $t = 1, \dots, T,$ the private firm operates at the output level where marginal revenue is equal to marginal costs: $\frac{a}{b} - \frac{2Q}{bN_t} = c,$ and the monopoly output in period t is given by

(6) $$Q_t^m = \frac{bN_t}{2}\left(\frac{a}{b} - c\right), \qquad (t = 1, \dots, T).$$

Note that $Q_t^m = \frac{1}{2} Q_t^*,$ i.e., in each period, the monopoly output is half of the socially optimal output. In privatizing the water project under a BOT contract the government gains by not having to make the capital investment, but loses in social welfare because the monopoly output is sub-optimal. The government should only privatize the water project if the gains are at least equal to the losses.

The profit made by the private firm in period t is given by

(7) $$\pi_t = \left(\frac{a}{b} - \frac{Q_t^m}{bN_t}\right) Q_t^m - cQ_t^m, \qquad (t = 1, \dots, T).$$

Social welfare in each period t during the duration of the BOT contract is given by

(8) $$\omega_t^m = \int_0^{Q_t^m} \left(\frac{a}{b} - \frac{Q}{bN_t}\right) dQ - cQ_t^m \qquad (t = 1, \dots, T).$$

The present value of the stream of monopoly profits during the duration of the BOT contract is given by

(9) $$\Pi = -K + \sum_{t=1}^{T} \delta^t \pi_t.$$

Note that in (9) we have assumed the private firm uses the same discount factor as the government in discounting future profits. A private firm will only participate in the infrastructure privatization if $\Pi \geq 0$.

The present value of the stream of social welfare obtained under the BOT contract is given by

(10) $$\Omega^m = \sum_{t=1}^{T} \delta^t \omega_t^m + \sum_{t=T+1}^{\overline{T}} \delta^t \omega_t^*.$$

Note that on the right-hand side of (10) the expression involving the first summation represents the present value of the stream of welfare during the duration of the BOT contract, when the private firm enjoys monopoly market power, while the expression involving the second summation represents the present value of the stream of social welfare after the transfer of the water treatment plant to the government.

As in the case of “not privatize”, we have also obtained – through the symbolic computational capability of *Mathematica* – the closed-form expressions for both Π and Ω^m, but have chosen not to reproduce them here.

7.3. To Privatize or not to Privatize

To decide whether or not the water project should be privatized, it is necessary to compare Ω^*, the social welfare without privatization and Ω^m, the social welfare with privatization. If $\Omega^* \leq \Omega^m$, the water project should be privatized. Otherwise, the government should keep the water project under public control.

Several factors play an important role in the decision of whether or not the water project should be privatized. First, if λ, the shadow cost of public funds is high – and this is the underpinning of the fiscal hypothesis – this factor operates in favor of privatization. Second, a high value of K, the capital investment, is also conducive to privatization. Third, whether a private firm is willing to participate in the privatization under the form of a BOT contract depends on Π, the present value of the stream of profits it obtains during the duration of the contract. A large and growing market raises the monopoly profits obtained in each period of the BOT contract and provides incentives for the private firm to participate. Fourth, whether a private firm is willing to sign a BOT contract also depends on the duration of the contract during which the firm is allowed to earn monopoly profit. A BOT contract with a long duration provides more incentive for the private firm to participate.

8. CALIBRATION OF A NUMERICAL BOT MODEL FOR URBAN WATER AND WASTEWATER PRIVATIZATION

In this section, we calibrate a BOT model for a water firm – among several in Shenzhen – to analyze empirically the issues involved in the privatization of a water project in a large city of China. The data used to estimate the model are gathered in Appendix A, Appendix B, and Appendix C of the paper. Appendix D contains the *Mathematica* program we have written to carry out the numerical as well as the symbolic computations involved in the calibration of the BOT model.

Appendix A contains the data on the prices of water of 21 cities and Tibet for the year 2014. In the calibration, we ignore Tibet. In most of these cities, the prices of water per cubic meter are segmented and expressed in RMB, the Chinese currency. When the price of water is segmented, it varies with consumption. For example, in Beijing, when a household consumes less than $180m^3$, it pays $5RMB$ per cubic meter. The price rises to $7RMB$ for consumption volumes between $180 - 260$ cubic meters. The water price rises further to $9RMB$ for any consumption level above 260 cubic meters. That is, in Beijing the expenditure on water consumption rises with the volume of consumption in a piecewise linear fashion, with the total cost consisting of three linear segments having, respectively, slopes of 5, 7, and 9. To fit a linear demand curve on the price-quantity data presented in Appendix A and Appendix B, it is necessary to compute a weighted price of water for each city. As an example, in the case of Beijing, the weighted price of water is computed as follows:

$$\frac{180}{180+(260-180)+100}\times 5+\frac{260-180}{180+(260-180)+100}\times 7 + \frac{180}{180+(260-180)+100}\times 9 = 6.55556 RMB/m^3.$$

Note that in the preceding calculations we have chosen in an arbitrary manner $[260, 260+100]$ as the interval over which the price per cubic meter of water is at its highest level.

Appendix B contains the 2014 data on residential water consumption in the 21 cities we consider. Because the residential consumption is expressed in units of $10000m^3$, it is necessary to express the water prices also for each unit of $10000m^3$. Table 1 presents the price-consumption data for the 21 cities we consider when units of water are in $10000m^3$.

Table 1: Cross-Section Price-Quantity Data for Residential Consumption (Year 2014)

City	**Price(RMB per10000m^3)**	**Residential Consumption (in $10000m^3$)**
Beijing	655556	76122
Tianjin	49000	24338
Shenyang	34263	20965
Shanghai	43210	102382
Guangzhou	34200	88722
Shenzhen	37250	91204
Nanjing	35338.9	36636
Hangzhou	18500	23733
Ningbo	46337	14606

Fuzhou	31535	13085
Xiamen	29785.7	13069
Chongqing	27000	50626
Taiyuan	45297	13286
Harbin	24000	15070
Hefei	15500	18757
Jinan	61628	12681
Qingdao	50098	11851
Zhengzhou	22500	11871
Wuhan	27735	48212
Changsha	25800	31263
Haikou	26898	9655

Figure 1 shows the plot of the data in Table 1.

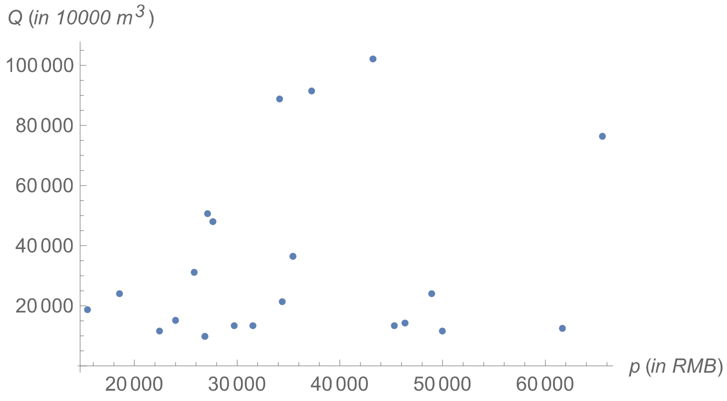

Figure 1.− Plot of price-residential consumption data

When we use the least-squares technique to fit a straight line that best fits the data points in Figure 1, the result we obtain is an upward sloping demand curve, which is not consistent with economic theory. This aberrant result, we believe, is cause by the data points in the up right corner of the figure. We shall not attempt to explain this anomaly because it is beyond the scope of the paper. To resolve this problem, we remove these outliers from the data set and then try to fit a straight line that best fits the smaller data set. The reduced data set is presented in Table 2.

Table 2: Reduced Cross-Section Price-Quantity Data for Residential Consumption (Year 2014)

City	**Price(RMB per10000m^3)**	**Residential Consumption (in $10000m^3$)**
Tianjin	49000	24338
Shenyang	34263	20965
Nanjing	35338.9	36636
Hangzhou	18500	23733
Ningbo	46337	14606
Fuzhou	31535	13085
Xiamen	29785.7	13069
Chongqing	27000	50626
Taiyuan	45297	13286
Harbin	24000	15070
Hefei	15500	18757

Jinan	61628	12681
Qingdao	50098	11851
Zhengzhou	22500	11871
Wuhan	27735	48212
Changsha	25800	31263
Haikou	26898	9655

Figure 2 shows the plot of the smaller data set.

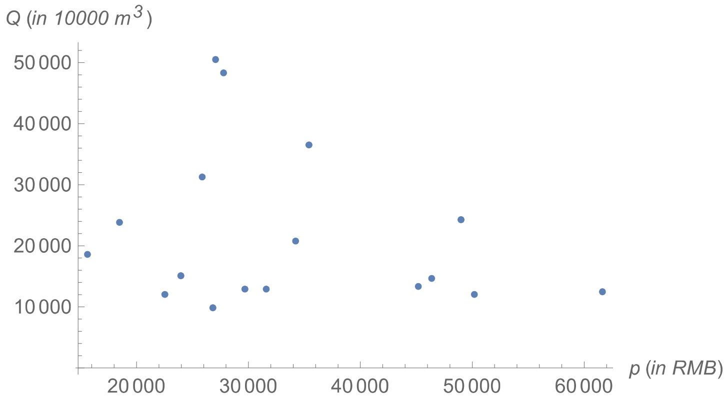

Figure 2.− Plot of price-residential consumption for the reduced data set

The straight line that best fits the data in Figure 2 gives us the following market demand curve for a city in China for the year 2014:

(11) $Q = 30009.5 - 0.245891\, p.$

Here p is the price per 10000 cubic meters and Q is the market demand at price p.

Appendix C contains the data on costs and revenues for a water plant in Shenzhen for 7 years, starting with the construction cost (capital investment) in year 0. We are not able to find out the date for each of these 7 years. The plant starts operating in year 1 with a loss of 9091353 RMB. The losses last for two more years, 4607384 RMB in year 2 and 4067384 RMB in year 3. The fortunes of the water plant start turning around in year 3 when it makes a net profit of 284255 RMB. The profits made by the water plant in years 4, 5, and 6 are 1390062 RMB, 1833190 RMB, and 6089968 RMB, respectively.

Without a definite date for year 6 of the table in Appendix C, we arbitrarily take 2014 as the date that corresponds to year 6 of the table in Appendix C. Under this assumption, year 5 and year 6 in the table in Appendix C correspond, respectively, to period $t = 0$ and period $t = 1$ of our BOT model, and according to Table 1, the price per 10000^3 of water in Shenzhen in period $t = 1$ is $37250RMB$.

Now assuming that the urban population is equal to 1 in period $t = 0$ and grows at rate n per annum,[29] we obtain the following market demand curve for an urban center in period t:

(12) $$Q(t) = (1+n)^{t-1}(30009.5 - 0.245891\, p), \qquad \left(t = 1, \dots, \overline{T}\right).$$

The choke price associated with the demand curves represented by (12) is

(13) $$\overline{p} = \frac{30009.5}{0.245891} = 122044.$$

[29] The projected growth rate is 2.69% in 2010.

Because the annual commercial loan interest of 2437674 RMB is counted as cost in Appendix C, it must be excluded from the calculation of marginal cost of the water plant. However, the discounted value of the stream of annual commercial loan interest (discounted to the year of construction) gives us the value of the loan needed to finance the construction of the water plant, i.e., the capital investment involved in this water project. Supposing that the duration of the BOT contract is $T = 20 years$ and that the loan must be completely paid off at the end of the BOT contract, we obtain the following value in RMB of the year of construction of the capital investment for the water project using an interest rate[30] of 4.35% to discount the stream of annual commercial loan interest: $34{,}563{,}000\ RMB.$ Adding the operating costs of 19,200,000 and the labor costs of 1,920,000 during the construction phase, we obtain the following value for the initial estimate of the project capital investment: $5.5683 \times 10^{7}\ RMB.$

Now for year 1 and year 2 in Appendix C, the water plant was operated at a loss. The loss in each of these two years includes the annual commercial loan interest of $2{,}437{,}674\ RMB.$ We shall consider these losses as the adjustment costs and count them as part of the capital investment for the project. Furthermore, to avoid double counting the annual commercial loan interest, we must subtract $2{,}437{,}674\ RMB$ from the loss in year 1 and the loss in year 2. Also, the table in Appendix C shows positive profits in years 3-5. Because we take year 5 as period $t = 0$ of the BOT model, we shall subtract the present value of the profits in years 3-5 from the initial estimate of the capital investment $5.5683 \times 10^{7}\ RMB$ to arrive at the following final

[30] This is the interest rate set by the People's Bank of China on 2015-10-23.

estimate of the construction cost of the plant in RMB of year 5 (or period $t = 0$ of the BOT model):

(14) $K = 5.49762 \times 10^7 RMB.$

The detailed computations involved in this final estimate of the construction cost can be found in the *Mathematica* program listed as Appendix D.

Now recall that we have taken year 6 in Appendix C as year 2014 and have identified year 2014 as period $t = 1$ of the BOT model. To calibrate the demand facing the private firm and its technology for period $t = 1$, note that according to the data in Appendix C, the total revenue made by the private firm in year 6 of the water project is 85048000 RMB. Using the water price per 10000^3 for residential consumption in Shenzhen in year 2014 (period $t = 1$) of our BOT model as the water price in period $t = 1,$ we have

(15) $p_1 = 37235\ RMB.$

The volume of water provided by the firm in period $t = 1$ is then given by

(16) $q_1 = \frac{85048000}{37250} = 2283.17,$

where q_1 is expressed in units of $10000m^3$.

The total cost (taxes included) of providing q_1 is

(17) $tc_1 = 5290720 + 41892096 + 1590000 + 7950000 + 7280000 +$

$$795000 + 130000 + 10198750 + 111294 + 1018949 + 263545$$

$= 76{,}520{,}354\ RMB.$

The average cost of water provision for each unit of 10000 cubic meters of water is then given by

(18) $c = \frac{tc_1}{q_1} = \frac{76{,}520{,}354}{2283.17} = 33515\ RMB.$

Now let

(19) $p = a - bQ$

denote the inverse demand curve faced by the private water firm in period $t = 1$. Here Q denotes market demand and p the water price at which market demand is equal to Q. Then $a = \overline{p} = 122044$, the choke price, and using $p_1 = 37235\ RMB$, $q_1 = 2283.17$ in (19), we obtain the following equation in b:

(20) $37250. = 122044. - 2283.17\ b.$

Solving (20) for b, we obtain

(21) $b = 37.1387.$

The explicit form for the inverse demand for water faced by the private firm in period $t = 1$ is

(22) $p = 122044 - 37.1387Q.$

Solving (22) for Q, we obtain the following ordinary version of the market demand curve facing the private water firm in period 1:

$$(23) Q_1 = 3286.16 - 0.0269261\, p.$$

Now assume that the number of households that have access to the water provided by the private firm begins at the level $N_1 = 1$ in period $t = 1$ and rises geometrically at the annual rate $n = 2.5\%$, we obtain the following ordinary market demand curve faced by the private water firm in period t of the BOT concession:

$$(24) Q_t = 1.025^{t-1}(3286.16 - 0.0269261\, p), \qquad (t = 1, \dots, T).$$

If the government chooses not to privatize the water project, then the optimal water tariff in each period of the useful life of the water plant at marginal cost. Thus setting $p = c = 33515$ in (24), we obtain the following expression for the socially optimal water output in period t:

$$(25) Q_t^* = 2325.6\, e^{0.0246926t}, \qquad (t = 1, \dots, T).$$

Using a rate of interest of $r = 4.35\%$ set by China's Central Bank to discount profits and welfare, we obtain the following discounted welfare net of construction cost under the choice of "not privatize the water project":

$$(26) \qquad \Omega^* = 3.37159 \times 10^9 - 6.80201 \times 10^7\,(1 + \lambda).$$

The water price that maximizes monopoly profit in each year of the BOT concession is obtained by solving the following maximization problem:

$$(27) max_p\,(p - c)Q_t = max_p(p - c)1.025^{t-1}(3286.16 - 0.0269261\, p).$$

This simple profit maximization problem yields the following water price in each year of the BOT concession:

$$(28) p_t^m = 77779.5\ RMB, \qquad (t = 1, \dots, T).$$

Note that the water price remains constant during the duration of the BOT concession. This special result is due to the linear structure of the model and the assumption of population's geometric growth. The constancy of the water price through time implies that each household consumes the same volume of water year after year, i.e., the volume of water supplied by the private water firm grows at the same rate as the population growth rate.

The monopoly water outputs for 20 years of the BOT concession are presented in the following Table 3.

Table 3: The Privatize Solution

Period (t)	Monopoly Output (Q_t^m in 10000 $cubic$ $meters$)
1	1191.87
2	1221.67
3	1252.21
4	1283.51
5	1315.6
6	1348.49
7	1382.2

8	1416.76
9	1452.18
10	1488.48
11	1525.69
12	1563.83
13	1602.93
14	1643
15	1684.08
16	1726.18
17	1769.34
18	1813.57
19	1858.91
20	1905.38

The discounted profit net of construction cost of the BOT concessionaire is given by

(29) $\Pi = 7.89664 \times 10^8\ RMB,$

which is positive; that is, the private water firm is willing to participate in the PPP.

The discounted social welfare obtained under the choice of "privatize the water project" is given by

(30) $\Omega^m = 2.94275 \times 10^9\ RMB.$

Figure 3 depicts the welfare differential between the choice of "not privatize" and the choice of "privatize" for a range of opportunity cost of public funds.

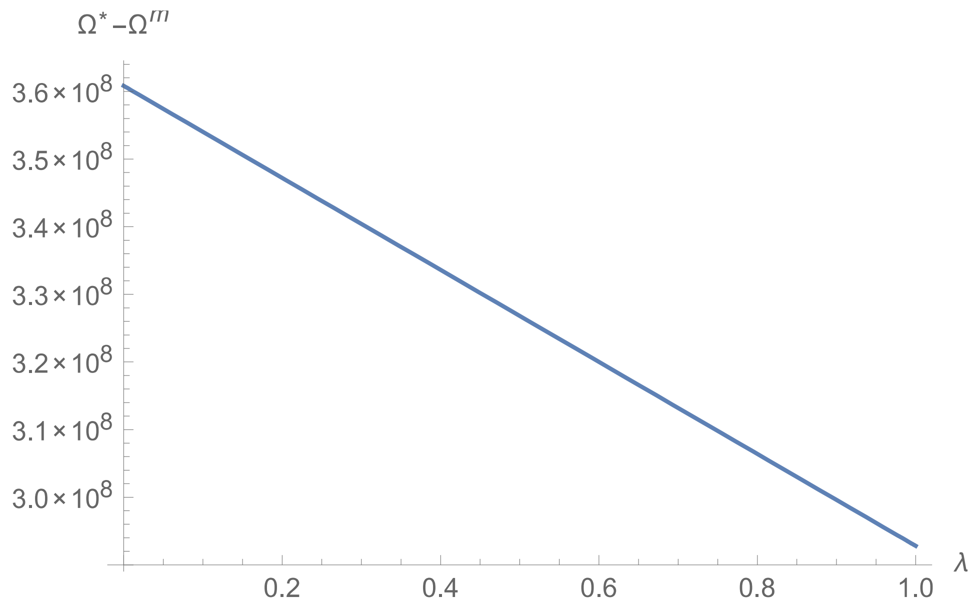

Figure 3.− The welfare differential between "not privatize" and "privatize"

As can be seen from Figure 3, the government obtains a higher level of social welfare if it carries out the water project itself than engaging in a PPP under the form of a BOT concession.

9. CONCLUSION

The literature on the privatization of China's urban water and wastewater is mainly descriptive and deals with the organization and governance of the PPP (Public-Private-Partnership). The literature represents the works of Chinese scholars who toil in the area of environmental studies and thus is not grounded in economics. The scholars in this field narrate water tariff reforms extensively without even mentioning the costs of water provision. Our paper is intended to provide a rigorous analysis of PPP under the form of a BOT contract from the perspective of cost-benefit analysis of traditional welfare economics. A water project should only be privatized if there is a welfare gain in adopting such a policy.

We have formalized a BOT model from the perspective of the fiscal hypothesis and calibrated the theoretical model using a limited data set comprising the revenues and costs of a private water firm in Shenzhen. Our numerical analysis indicates that privatizing a water project under the form of a BOT concession that grants full monopoly power to a concessionaire for a length of 20 years is not socially optimal. In maximizing monopoly profits the concessionaire restricts output to half of the socially optimal level, which is translated into a water tariff that is more than twice that under the social optimum. Our numerical analysis confirms the proposition that water is essential for life and its demand does not vary much as price rises. Furthermore, because water is essential for life, it is widely believed that it should be provided at little or no cost, and any effort by the public authorities to reform the water sector by raising the water tariff will meet ferocious political opposition from consumers. In avoiding to pay the political cost of loss of popular support, the government often controls the water price at a level that is so low that private firms are unable to recover costs, leading to repeated renegotiations or abandonment of the partnership. A solution to this problem is to control price so that the deadweight loss is significantly reduced while still providing incentives for the private sector to participate. In our discussion of the efficiency gain associated with privatization, it is mentioned that the gain in efficiency of PPP is ambiguous. We have already suggested that a missing variable in the efficiency hypothesis is human capital, which is the driving of growth from the endogenous growth literature. In traducing human capital into a model of PPP might be the next item on the research agenda.

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APPENDIX

APPENDIX A
Water Pricing 2014
From China Water Pricing (price.h2o-china.com)

City	Segmentation	Use Level(cubic meter per family)	Pricing RMB
Beijing	Level 1	180 and Below	**5.00**
	Level 2	181-260	**7.00**
	Level 3	260 and Above	**9.00**
Tianjin	No Segmentation		**4.90**
Shenyang	Level 1	144 and Below	**2.40**
	Level 2	145-204	**3.60**
	Level 3	204 and Above	**4.80**
Shanghai	Level 1	220 and Below	**3.45**
	Level 2	220-300	**4.83**
	Level 3	300 and Above	**5.83**
Guangzhou	Level 1	312 and Below	**2.79**
	Level 2	312-324	**4.05**
	Level 3	324 and Above	**5.31**
Shenzhen	Level 1	220 and Below	**3.00**
	Level 2	220-300	**3.50**
	Level 3	300 and Above	**5.50**
Nanjing	Level 1	240 and Below	**3.10**
	Level 2	240-260	**3.81**
	Level 3	260 and Above	**4.52**
Hangzhou	No Segmentation		**1.85**
Ningbo	Level 1	204 and Below	**3.20**
	Level 2	201-360	**5.12**
	Level 3	360 and Above	**6.80**
Fuzhou	Level 1	216 and Below	**2.55**
	Level 2	216-300	**3.40**
	Level 3	300 and Above	**4.25**
Xiamen	Level 1	180 and Below	**2.80**
	Level 2	180 and Above	**3.30**
Chongqing	No Segmentation		**2.70**
Taiyuan	Level 1	108 and Below	**2.30**
	Level 2	108-162	**4.60**
	Level 3	162 and Above	**6.90**
Harbin	No Segmentation		**2.40**

Hefei	No Segmentation		**1.55**
Jinan	Level 1	144 and Below	**4.20**
	Level 2	144-288	**5.60**
	Level 3	288 and Above	**9.80**
Qingdao	Level 1	144 and Below	**3.00**
	Level 2	144-204	**4.85**
	Level 3	204 and Above	**8.00**
Zhengzhou	No Segmentation		**2.25**
Wuhan	Level 1	300 and Below	**2.32**
	Level 2	300-396	**3.08**
	Level 3	396 and Above	**3.84**
Changsha	No Segmentation		**2.58**
Haikou	Level 1	264 and Below	**1.75**
	Level 2	264-396	**2.63**
	Level 3	396 and Above	**5.25**
Tibet	No Segmentation		**0.60**

APPENDIX B

2014 water supply and water consumption for residential use (districts under city)

From China City Statistical Yearbook

City	Water supply(10,000 ton)	Water demand(10,000 ton)
Beijing	189386	76122
Tianjin	78631	24338
Shenyang	54879	20965
Shanghai	319072	102382
Guangzhou	196329	88722
Shenzhen	159139	91204
Nanjing	126656	36636
Hangzhou	60747	23733
Ningbo	47309	14606
Fuzhou	33596	13085
Xiamen	38638	13069
Chongqing	104996	50626
Taiyuan	32348	13286
Harbin	35731	15070
Hefei	37596	18757
Jinan	33569	12681
Qingdao	38331	11851
Zhengzhou	35413	11871
Wuhan	126257	48212

Changsha	52739	31263
Haikou	20293	9655
Tibet	11280	4065

APPENDIX C

Cost Accounting of Shenzhen Water Group （All currency in RMB）

From Guangdong Water Supply Association (http://www.gdwsa.com/)

Cost	Project construction phase	1st year
Revenue	0	63072000.00
Depreciation	0	5290720.50
Annual operation costs	19200000.00	37943750.00
Maintenance fee	0	1590000.00
Material cost	0	7950000.00
Labour cost	1920000.00	7280000.00
Management fee	0	795000.00
water resources	0	130000.00
Electricity	0	10198750.00
Commercial loan interest	2437674.12	2437674.12
General tax	0	0
Enterprise income tax	0	(1134800.41)
Sales tax	0	(317740.51)
Net benefit	**-23557674.12**	**-9091353.70**

2nd year	3rd year	4th year	5th year	6th year
68072000.00	76402000.00	79025000.00	80025800.00	85048000.00
5290720.50	5290720.50	5290720.50	5290720.50	5290720.50
38702620.50	39470667.75	40266021.11	41007153.53	41892096.60
1590000.00	1590000.00	1590000.00	1590000.00	1590000.00
7950000.00	7950000.00	7950000.00	7950000.00	7950000.00
7280000.00	7280000.00	7280000.00	7280000.00	7280000.00
795000.00	795000.00	795000.00	795000.00	795000.00
130000.00	130000.00	130000.00	130000.00	130000.00
10198750.00	10198750.00	10198750.00	10198750.00	10198750.00
2437674.12	2437674.12	2437674.12	2437674.12	2437674.12
0	98616.20	163351.13	137580.75	111294.97
(1324520.28)	723056.41	1176118.07	1074784.96	1018949.20
(370860.64)	153259.79	357303.06	300945.79	263545.77
-4607384.20	**284255.23**	**1390062.01**	**1833190.35**	**6089968.84**

APPENDIX D

Calibration of the Theoretical BOT Model

1. Residential Consumption: Cross-Section Water Prices Data

```
In[1]:= p[x1_, x2_, x3_, p1_, p2_, p3_] :=
         (x1 p1 + (x2 - x1) p2 + (x3 - x2) p3) / (x1 + (x2 - x1) + (x3 - x2))

In[2]:= a[1] = {Beijing, p[180, 260, 360, 5.0, 7.0, 9.0]}
Out[2]= {Beijing, 6.55556}

In[3]:= a[2] = {Tianjin, 4.90}
Out[3]= {Tianjin, 4.9}

In[4]:= a[3] = {Shenyang, p[144, 204, 304, 2.40, 3.60, 4.80]}
Out[4]= {Shenyang, 3.42632}

In[5]:= a[4] = {Shanghai, p[220, 300, 400, 3.45, 4.83, 5.83]}
Out[5]= {Shanghai, 4.321}

In[6]:= a[5] = {Guangzhou, p[312, 324, 424, 2.79, 4.05, 5.31]}
Out[6]= {Guangzhou, 3.42}

In[7]:= a[6] = {Shenzhen, p[220, 300, 400, 3.00, 3.50, 5.50]}
Out[7]= {Shenzhen, 3.725}

In[8]:= a[7] = {Nanjing, p[240, 260, 360, 3.10, 3.81, 4.52]}
Out[8]= {Nanjing, 3.53389}

In[9]:= a[8] = {Hangzhou, 1.85}
Out[9]= {Hangzhou, 1.85}

In[10]:= a[9] = {Ningbo, p[204, 360, 460, 3.20, 5.12, 6.80]}
Out[10]= {Ningbo, 4.63374}

In[11]:= a[10] = {Fuzhou, p[216, 300, 400, 2.55, 3.40, 4.25]}
Out[11]= {Fuzhou, 3.1535}

In[12]:= a[11] = {Xiamen, p[180, 180, 280, 2.80, 3.30, 3.30]}
Out[12]= {Xiamen, 2.97857}
```

```
In[13]:= a[12] = {Chongqing, 2.70}

Out[13]= {Chongqing, 2.7}

In[14]:= a[13] = {Taiyuan, p[108, 162, 262, 2.30, 4.60, 6.90]}

Out[14]= {Taiyuan, 4.52977}

In[15]:= a[14] = {Harbin, 2.40}

Out[15]= {Harbin, 2.4}

In[16]:= a[15] = {Hefei, 1.55}

Out[16]= {Hefei, 1.55}

In[17]:= a[16] = {Jinan, p[144, 288, 388, 4.20, 5.60, 9.80]}

Out[17]= {Jinan, 6.16289}

In[18]:= a[17] = {Qingdao, p[144, 204, 304, 3.00, 4.85, 8.00]}

Out[18]= {Qingdao, 5.00987}

In[19]:= a[18] = {Zhengzhou, 2.25}

Out[19]= {Zhengzhou, 2.25}

In[20]:= a[19] = {Wuhan, p[300, 396, 496, 2.32, 3.08, 3.84]}

Out[20]= {Wuhan, 2.77355}

In[21]:= a[20] = {Changsha, 2.58}

Out[21]= {Changsha, 2.58}

In[22]:= a[21] = {Haikou, p[264, 396, 496, 1.75, 2.63, 5.25]}

Out[22]= {Haikou, 2.68984}

In[23]:= t[0] = Table[a[i], {i, 1, 21}]

Out[23]= {{Beijing, 6.55556}, {Tianjin, 4.9}, {Shenyang, 3.42632},
  {Shanghai, 4.321}, {Guangzhou, 3.42}, {Shenzhen, 3.725},
  {Nanjing, 3.53389}, {Hangzhou, 1.85}, {Ningbo, 4.63374},
  {Fuzhou, 3.1535}, {Xiamen, 2.97857}, {Chongqing, 2.7}, {Taiyuan, 4.52977},
  {Harbin, 2.4}, {Hefei, 1.55}, {Jinan, 6.16289}, {Qingdao, 5.00987},
  {Zhengzhou, 2.25}, {Wuhan, 2.77355}, {Changsha, 2.58}, {Haikou, 2.68984}}
```

In[24]:=
```
t[0] // MatrixForm
```

Out[24]//MatrixForm=

Beijing	6.55556
Tianjin	4.9
Shenyang	3.42632
Shanghai	4.321
Guangzhou	3.42
Shenzhen	3.725
Nanjing	3.53389
Hangzhou	1.85
Ningbo	4.63374
Fuzhou	3.1535
Xiamen	2.97857
Chongqing	2.7
Taiyuan	4.52977
Harbin	2.4
Hefei	1.55
Jinan	6.16289
Qingdao	5.00987
Zhengzhou	2.25
Wuhan	2.77355
Changsha	2.58
Haikou	2.68984

2. Residential Price-Consumption Cross-Section Data

In[25]:=
```
a[1]
```

Out[25]= {Beijing, 6.55556}

In[26]:=
```
b[1] = {Beijing, 6.555555555555556`, 76 122}
```

Out[26]= {Beijing, 6.55556, 76 122}

In[27]:=
```
a[2]
```

Out[27]= {Tianjin, 4.9}

In[28]:=
```
b[2] = {Tianjin, 4.9`, 24 338}
```

Out[28]= {Tianjin, 4.9, 24 338}

In[29]:=
```
a[3]
```

Out[29]= {Shenyang, 3.42632}

In[30]:=
```
b[3] = {Shenyang, 3.4263157894736835`, 20 965}
```

Out[30]= {Shenyang, 3.42632, 20 965}

In[31]:=
```
a[4]
```

Out[31]= {Shanghai, 4.321}

In[32]:=
```
b[4] = {Shanghai, 4.321000000000001`, 102 382}
```

Out[32]= {Shanghai, 4.321, 102 382}

```
In[33]:= a[5]
Out[33]= {Guangzhou, 3.42}
In[34]:= b[5] = {Guangzhou, 3.4199999999999995`, 88722}
Out[34]= {Guangzhou, 3.42, 88722}
In[35]:= a[6]
Out[35]= {Shenzhen, 3.725}
In[36]:= b[6] = {Shenzhen, 3.725`, 91204}
Out[36]= {Shenzhen, 3.725, 91204}
In[37]:= a[7]
Out[37]= {Nanjing, 3.53389}
In[38]:= b[7] = {Nanjing, 3.5338888888888893`, 36636}
Out[38]= {Nanjing, 3.53389, 36636}
In[39]:= a[8]
Out[39]= {Hangzhou, 1.85}
In[40]:= b[8] = {Hangzhou, 1.85`, 23733}
Out[40]= {Hangzhou, 1.85, 23733}
In[41]:= a[9]
Out[41]= {Ningbo, 4.63374}
In[42]:= b[9] = {Ningbo, 4.633739130434782`, 14606}
Out[42]= {Ningbo, 4.63374, 14606}
In[43]:= a[10]
Out[43]= {Fuzhou, 3.1535}
In[44]:= b[10] = {Fuzhou, 3.1534999999999997`, 13085}
Out[44]= {Fuzhou, 3.1535, 13085}
In[45]:= a[11]
Out[45]= {Xiamen, 2.97857}
In[46]:= b[11] = {Xiamen, 2.9785714285714286`, 13069}
Out[46]= {Xiamen, 2.97857, 13069}
In[47]:= a[12]
Out[47]= {Chongqing, 2.7}
```

```
In[48]:= b[12] = {Chongqing, 2.7`, 50 626}
Out[48]= {Chongqing, 2.7, 50 626}

In[49]:= a[13]
Out[49]= {Taiyuan, 4.52977}

In[50]:= b[13] = {Taiyuan, 4.529770992366412`, 13 286}
Out[50]= {Taiyuan, 4.52977, 13 286}

In[51]:= a[14]
Out[51]= {Harbin, 2.4}

In[52]:= b[14] = {Harbin, 2.4`, 15 070}
Out[52]= {Harbin, 2.4, 15 070}

In[53]:= a[15]
Out[53]= {Hefei, 1.55}

In[54]:= b[15] = {Hefei, 1.55`, 18 757}
Out[54]= {Hefei, 1.55, 18 757}

In[55]:= a[16]
Out[55]= {Jinan, 6.16289}

In[56]:= b[16] = {Jinan, 6.162886597938145`, 12 681}
Out[56]= {Jinan, 6.16289, 12 681}

In[57]:= a[17]
Out[57]= {Qingdao, 5.00987}

In[58]:= b[17] = {Qingdao, 5.009868421052631`, 11 851}
Out[58]= {Qingdao, 5.00987, 11 851}

In[59]:= a[18]
Out[59]= {Zhengzhou, 2.25}

In[60]:= b[18] = {Zhengzhou, 2.25`, 11 871}
Out[60]= {Zhengzhou, 2.25, 11 871}

In[61]:= a[19]
Out[61]= {Wuhan, 2.77355}

In[62]:= b[19] = {Wuhan, 2.773548387096774`, 48 212}
Out[62]= {Wuhan, 2.77355, 48 212}
```

```
In[63]:= a[20]

Out[63]= {Changsha, 2.58}

In[64]:= b[20] = {Changsha, 2.58`, 31 263}

Out[64]= {Changsha, 2.58, 31 263}

In[65]:= a[21]

Out[65]= {Haikou, 2.68984}

In[66]:= b[21] = {Haikou, 2.689838709677419`, 9655}

Out[66]= {Haikou, 2.68984, 9655}

In[67]:= t[1] = Table[b[i], {i, 1, 21}]

Out[67]= {{Beijing, 6.55556, 76 122}, {Tianjin, 4.9, 24 338}, {Shenyang, 3.42632, 20 965},
 {Shanghai, 4.321, 102 382}, {Guangzhou, 3.42, 88 722}, {Shenzhen, 3.725, 91 204},
 {Nanjing, 3.53389, 36 636}, {Hangzhou, 1.85, 23 733}, {Ningbo, 4.63374, 14 606},
 {Fuzhou, 3.1535, 13 085}, {Xiamen, 2.97857, 13 069}, {Chongqing, 2.7, 50 626},
 {Taiyuan, 4.52977, 13 286}, {Harbin, 2.4, 15 070}, {Hefei, 1.55, 18 757},
 {Jinan, 6.16289, 12 681}, {Qingdao, 5.00987, 11 851}, {Zhengzhou, 2.25, 11 871},
 {Wuhan, 2.77355, 48 212}, {Changsha, 2.58, 31 263}, {Haikou, 2.68984, 9655}}

In[68]:= t[1] // MatrixForm

Out[68]//MatrixForm=
```

Beijing	6.55556	76 122
Tianjin	4.9	24 338
Shenyang	3.42632	20 965
Shanghai	4.321	102 382
Guangzhou	3.42	88 722
Shenzhen	3.725	91 204
Nanjing	3.53389	36 636
Hangzhou	1.85	23 733
Ningbo	4.63374	14 606
Fuzhou	3.1535	13 085
Xiamen	2.97857	13 069
Chongqing	2.7	50 626
Taiyuan	4.52977	13 286
Harbin	2.4	15 070
Hefei	1.55	18 757
Jinan	6.16289	12 681
Qingdao	5.00987	11 851
Zhengzhou	2.25	11 871
Wuhan	2.77355	48 212
Changsha	2.58	31 263
Haikou	2.68984	9655

```
In[69]:= t[2] = Table[{b[i][[1]], b[i][[2]] 10 000, b[i][[3]]}, {i, 1, 21}]

Out[69]= {{Beijing, 65 555.6, 76 122}, {Tianjin, 49 000., 24 338}, {Shenyang, 34 263.2, 20 965},
 {Shanghai, 43 210., 102 382}, {Guangzhou, 34 200., 88 722}, {Shenzhen, 37 250., 91 204},
 {Nanjing, 35 338.9, 36 636}, {Hangzhou, 18 500., 23 733}, {Ningbo, 46 337.4, 14 606},
 {Fuzhou, 31 535., 13 085}, {Xiamen, 29 785.7, 13 069}, {Chongqing, 27 000., 50 626},
 {Taiyuan, 45 297.7, 13 286}, {Harbin, 24 000., 15 070}, {Hefei, 15 500., 18 757},
 {Jinan, 61 628.9, 12 681}, {Qingdao, 50 098.7, 11 851}, {Zhengzhou, 22 500., 11 871},
 {Wuhan, 27 735.5, 48 212}, {Changsha, 25 800., 31 263}, {Haikou, 26 898.4, 9655}}
```

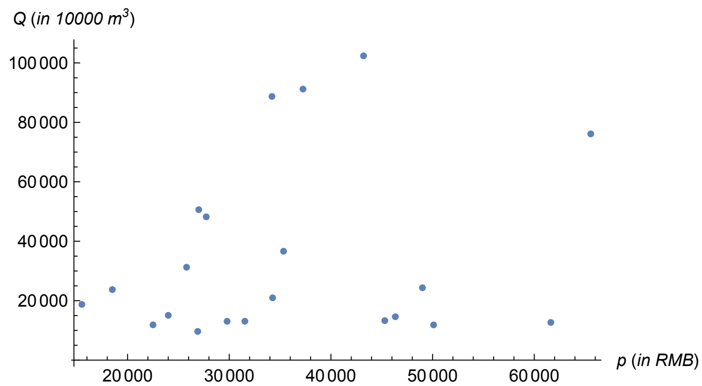
3. Residential Price-Consumption Cross-Section Data for Regression

In[70]:=
```
t[3] = Table[{b[i][[2]] 10 000, b[i][[3]]} , {i, 1, 21}]
```

Out[70]=
```
{{65 555.6, 76 122}, {49 000., 24 338}, {34 263.2, 20 965},
 {43 210., 102 382}, {34 200., 88 722}, {37 250., 91 204},
 {35 338.9, 36 636}, {18 500., 23 733}, {46 337.4, 14 606},
 {31 535., 13 085}, {29 785.7, 13 069}, {27 000., 50 626}, {45 297.7, 13 286},
 {24 000., 15 070}, {15 500., 18 757}, {61 628.9, 12 681}, {50 098.7, 11 851},
 {22 500., 11 871}, {27 735.5, 48 212}, {25 800., 31 263}, {26 898.4, 9655}}
```

In[71]:=
```
ListPlot[t[3], AxesLabel → {"p (in RMB)", "Q (in 10000 m³)"}]
```

Out[71]=



4. Linear Regression of Original Data: Upward Sloping Demand Curve (Rejected)

In[72]:=
```
Fit[t[3], {1, p}, p]
```

Out[72]=
```
18 945.3 + 0.439536 p
```

5. Reduced Data (After Removal of Outliers)

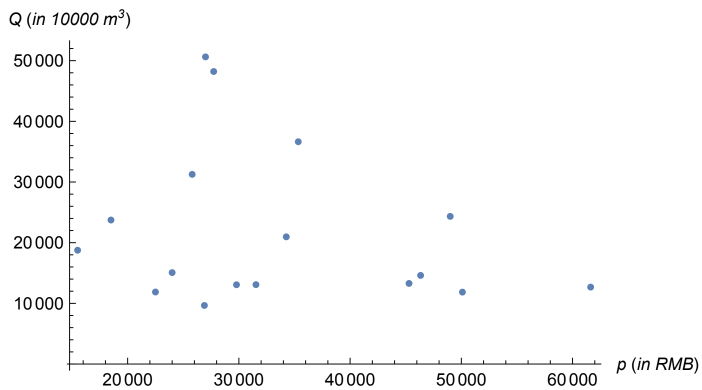
In[73]:=
```
t[4] = {{Tianjin, 49000.`, 24 338},
  {Shenyang, 34263.15789473683`, 20 965}, {Nanjing, 35338.88888888889`, 36 636},
  {Hangzhou, 18500.`, 23 733}, {Ningbo, 46337.391304347824`, 14 606},
  {Fuzhou, 31534.999999999996`, 13 085}, {Xiamen, 29785.714285714286`, 13 069},
  {Chongqing, 27000.`, 50 626}, {Taiyuan, 45297.70992366412`, 13 286},
  {Harbin, 24000.`, 15 070}, {Hefei, 15500.`, 18 757},
  {Jinan, 61628.865979381444`, 12 681}, {Qingdao, 50098.68421052631`, 11 851},
  {Zhengzhou, 22500.`, 11 871}, {Wuhan, 27735.483870967742`, 48 212},
  {Changsha, 25800.`, 31 263}, {Haikou, 26898.38709677419`, 9655}}
```

Out[73]=
```
{{Tianjin, 49 000., 24 338}, {Shenyang, 34 263.2, 20 965},
 {Nanjing, 35 338.9, 36 636}, {Hangzhou, 18 500., 23 733}, {Ningbo, 46 337.4, 14 606},
 {Fuzhou, 31 535., 13 085}, {Xiamen, 29 785.7, 13 069}, {Chongqing, 27 000., 50 626},
 {Taiyuan, 45 297.7, 13 286}, {Harbin, 24 000., 15 070}, {Hefei, 15 500., 18 757},
 {Jinan, 61 628.9, 12 681}, {Qingdao, 50 098.7, 11 851}, {Zhengzhou, 22 500., 11 871},
 {Wuhan, 27 735.5, 48 212}, {Changsha, 25 800., 31 263}, {Haikou, 26 898.4, 9655}}
```

In[74]:=
```
Length[t[4]]
```
Out[74]= 17

In[75]:=
```
data = Table[{t[4][[i, 2]], t[4][[i, 3]]}, {i, 1, 17}]
```
Out[75]=
```
{{49 000., 24 338}, {34 263.2, 20 965}, {35 338.9, 36 636},
 {18 500., 23 733}, {46 337.4, 14 606}, {31 535., 13 085},
 {29 785.7, 13 069}, {27 000., 50 626}, {45 297.7, 13 286},
 {24 000., 15 070}, {15 500., 18 757}, {61 628.9, 12 681}, {50 098.7, 11 851},
 {22 500., 11 871}, {27 735.5, 48 212}, {25 800., 31 263}, {26 898.4, 9655}}
```

In[76]:=
```
ListPlot[data, AxesLabel → {"p (in RMB)", "Q (in 10000 m^3)"}]
```
Out[76]=



In[77]:=
```
demand = Fit[data, {1, p}, p]
```
Out[77]= 30 009.5 - 0.245891 p

Demand curve is downward sloping: OK. The demand curve

$$Q[p] = 30\,009.5 - 0.245891\, p$$

is assumed to be the market demand curve for water by the households in a city in period 0. The market demand curve shifts to the right (it rotates counterclockwise around the choke price) through time.

6. Capital Investment

The present value of the stream of commercial loan interest (the rate of discount is 4.35% per annum, set by the People's Bank of China

In[78]:= $\text{Sum}\left[\frac{2\,437\,674}{1.0435^t}, \{t, 0, 20\}\right]$

Out[78]= 3.4563×10^7

Adding the operating costs of 19200000 and the labor costs of 1920000 to the preceding present value we obtain the following value for the project capital investment:

In[79]:=
```
% + 19 200 000 + 1 920 000
```
Out[79]= 5.5683×10^7

For year 1 and year 2 the water plant was operated at a loss. The loss in each of these two years include the annual commercial loan interest of 2437674. We shall consisder these costs as the adjustment costs and count them as part of the capital investment for the project. Furthermore, to avoid double counting the annual commercial loan interest, we must subtract 2437674 RMB from the loss in year 1 and the loss in year 2. Thus, the capital investment associated with the water project is

In[80]:= $$K = \% + \frac{(9\,091\,353 - 2\,437\,674)}{1.0435} + \frac{(4\,607\,384 - 2\,437\,674)}{1.0435^2}$$

Out[80]= 6.40519×10^7

Removing the annual commercial loan interest from the costs in years 3-5, we obtain the following present value for the profits in years 3-5:

In[81]:= $$\frac{(284\,255 + 2\,437\,674)}{1.0435^3} + \frac{(1\,390\,062 + 2\,437\,674)}{1.0435^4} + \frac{(1\,833\,190 + 2\,437\,674)}{1.0435^5}$$

Out[81]= 9.07567×10^6

Subtracting the present value for the profits in years 3-5 from *k*, we obtain the following amount that we interprete as the capital investment before year 6, the year we presume that the water project is fully functional.

In[82]:= **K = K - %**

Out[82]= 5.49762×10^7

The construction cost of the water plant expressed in RMB of year 5 of the water project

In[83]:= $K = 1.0435^5\, K$

Out[83]= 6.80201×10^7

7. Calibration of the Water Demand Curve Facing the Shenzhen Private Firm

To lighten the computations associated with the BOT contract, we collapse the project construction phase together with years 1-5 into a single period called period 0 and then consider year 6 as period $t = 1$ of the BOT concession. Also, we presume that the water plant is fully functional from period $t = 1$ (year 6 of the table in Appendix C)) until the end of its useful lifetime $\overline{T}$. According Table 1, the water price in period $t = 1$ in Shenzhen is

In[84]:= **p1 = 37 250.00**

Out[84]= 37 250.

The total revenue earned by the private water firm in period $t = 1$ is

In[85]:= **tr1 = 85 048 000.00**

Out[85]= 8.5048×10^7

The output of the private water firm in period $t = 1$ is

In[86]:= $$q1 = \frac{tr1}{p1}$$

Out[86]= 2283.17

The total cost (taxes included) incurred by the private water firm in period $t = 1$ is

In[87]:= **tc1 = 5 290 720 + 41 892 096 + 1 590 000 + 7 950 000 + 7 280 000 + 795 000 + 130 000 + 10 198 750 + 111 294 + 1 018 949 + 263 545**

Out[87]= 76 520 354

The avearage cost incurred by the private water firm in period $t = 1$ is

```
In[88]:= c = tc1/q1
Out[88]= 33 515.
```

The choke price of water in Shenzhen is

```
In[89]:= eq[0] = 30009.511251789816` - 0.24589101829838986` p == 0
Out[89]= 30 009.5 - 0.245891 p == 0

In[90]:= s[0] = Solve[eq[0], p] // Flatten
Out[90]= {p → 122 044.}
```

The inverse water demand curve for a household in Shenzhen in period $t = 1$ is assumed to be

```
In[91]:= p = a - b q
Out[91]= a - b q
```

The choke price of water is

```
In[92]:= a = p /. s[0]
Out[92]= 122 044.

In[93]:= p
Out[93]= 122 044. - b q

In[94]:= eq[1] = p1 == (p /. q → q1)
Out[94]= 37 250. == 122 044. - 2283.17 b

In[95]:= s[1] = Solve[eq[1], b] // Flatten
Out[95]= {b → 37.1387}

In[96]:= b = b /. s[1]
Out[96]= 37.1387
```

The inverse demand curve for water faced by the Shenzhen water firm in period $t = 1$ is

```
In[97]:= p
Out[97]= 122 044. - 37.1387 q
```

8. The Monopoly Solution in Period $t = 1$

The total revenue of the private water firm in period $t = 1$ is

```
In[98]:= tr = p q
Out[98]= (122 044. - 37.1387 q) q
```

The marginal revenue of the private water firm in period $t = 1$ is

In[99]:=
```
mr = ∂q tr
```
Out[99]= $122044. - 74.2775\, q$

In[100]:=
```
c
```
Out[100]= $33515.$

The rule for profit maximization in period 1: marginal revenue = marginal cost

In[101]:=
```
eq[2] = mr == c
```
Out[101]= $122044. - 74.2775\, q == 33515.$

The output level that maximizes monopoly profit in period $t = 1$

In[102]:=
```
s[2] = Solve[eq[2], q] // Flatten
```
Out[102]= $\{q \to 1191.87\}$

The monopoly obtained ter by the private firm in period $t = 1$, if it allowed to practice monopoly power, is given by

In[103]:=
```
(p - c) q /. s[2]
```
Out[103]= 5.27574×10^{7}

In[104]:=
```
ClearAll[p, q]
```

9. The Monopoly Solution in Period $t \geq 1$

In[105]:=
```
eq[3] = p == 122043.95044382279` - 37.138729353216995` q
```
Out[105]= $p == 122044. - 37.1387\, q$

In[106]:=
```
s[3] = Solve[eq[3], q] // Flatten // Expand
```
Out[106]= $\{q \to 3286.16 - 0.0269261\, p\}$

The demand for water faced by the private firm in period $t = 1$ is given by

In[107]:=
```
Q1 = q /. s[3]
```
Out[107]= $3286.16 - 0.0269261\, p$

The demand for water faced by the private firm in period $t \geq 1$ is given by

In[108]:=
```
Qt = 1.025^(t-1) Q1
```
Out[108]= $1.025^{-1+t}\, (3286.16 - 0.0269261\, p)$

The profit function of the private firm in period t is given by

In[109]:=
```
profit = Qt (p - c)
```
Out[109]= $1.025^{-1+t}\, (3286.16 - 0.0269261\, p)\, (-33515. + p)$

In[110]:=
```
eq[4] = D[profit, p] == 0 // FullSimplify
```
Out[110]= $1.025^{t}\, (-77779.5 + 1.\, p) == 0$

In[111]:=
```
s[4] = Solve[eq[4], p] // Flatten
```
Out[111]=
```
{p → 77 779.5}
```

Under the BOT concession the price that the private firms sets in each period to maximize profit is constrant and given by {$p \to 77\,779.5$}. The water outputs for periods t, $t = 1, 20$, of the BOT concession are presented in the following list:

In[112]:=
```
sm = Table[Qt /. s[4], {t, 1, 20}]
```
Out[112]=
```
{1191.87, 1221.67, 1252.21, 1283.51, 1315.6, 1348.49,
 1382.2, 1416.76, 1452.18, 1488.48, 1525.69, 1563.83, 1602.93,
 1643., 1684.08, 1726.18, 1769.34, 1813.57, 1858.91, 1905.38}
```

The discount factor

In[113]:=
$$\delta = \frac{1}{1.0435}$$
Out[113]=
```
0.958313
```

Suppose that the length of the BOT contract is $T = 20$ years. The present value of the stream of profits earned by the Shenzhen private firm under the BOT contract is

In[114]:=
```
PVprofit = Sum[δ^t (profit /. s[4]), {t, 1, 20}]
```
Out[114]= 8.57684×10^{8}

The present value of the stream of profits earned by the Shenzhen private firm under the BOT contract minus the capital investment is

In[115]:=
```
PVprofit - K
```
Out[115]= 7.89664×10^{8}

In[116]:=
```
ClearAll[Q, p]
```

The inverse demand for water faced by the private water firm in period t

In[117]:=
```
eq[5] = 1.025`^(-1+t) (3286.1638663803997` - 0.02692606929249665` p) == Q
```
Out[117]= $1.025^{-1+t}\,(3286.16 - 0.0269261\,p) == Q$

In[118]:=
```
s[5] = Solve[eq[5], p] // Flatten
```
Out[118]= $\{p \to -37.1387\; 1.025^{1.-1.\,t}\,(-3286.16\; 1.025^{-1.+t} + 1.\,Q)\}$

In[119]:=
```
p = p /. s[5]
```
Out[119]= $-37.1387\; 1.025^{1.-1.\,t}\,(-3286.16\; 1.025^{-1.+t} + 1.\,Q)$

In[120]:=
```
s[6] = Solve[p == c, Q] // Flatten // FullSimplify
```
Out[120]= $\{Q \to 2325.6\, e^{0.0246926\,t}\}$

In[121]:=
```
Qopt = Q /. s[6]
```
Out[121]= $2325.6\, e^{0.0246926\,t}$

In[122]:=
```
sopt = Table[Qopt, {t, 1, 50}]
```

Out[122]=
```
{2383.74, 2443.33, 2504.41, 2567.02, 2631.2, 2696.98, 2764.4, 2833.51, 2904.35,
 2976.96, 3051.38, 3127.67, 3205.86, 3286.01, 3368.16, 3452.36, 3538.67,
 3627.14, 3717.82, 3810.76, 3906.03, 4003.68, 4103.77, 4206.37, 4311.53,
 4419.31, 4529.8, 4643.04, 4759.12, 4878.1, 5000.05, 5125.05, 5253.18, 5384.51,
 5519.12, 5657.1, 5798.52, 5943.49, 6092.07, 6244.38, 6400.49, 6560.5,
 6724.51, 6892.62, 7064.94, 7241.56, 7422.6, 7608.17, 7798.37, 7993.33}
```

Social welfare in each period *t*, as a function of water consumption

In[123]:= $\omega = \int_0^x (p - c)\, dQ$

Out[123]= $0. + 88529.\, x - 18.5694 \times 1.025^{1.-1.\, t}\, x^2$

In[124]:= $\Omega opt = Sum\left[\delta^t\, (\omega \,/.\, x \to Qopt),\ \{t, 1, 50\}\right] - (1 + \lambda)\, K$

Out[124]= $3.37159 \times 10^9 - 6.80201 \times 10^7\, (1 + \lambda)$

In[125]:= ω

Out[125]= $0. + 88529.\, x - 18.5694 \times 1.025^{1.-1.\, t}\, x^2$

In[126]:= $\Omega m = Sum\left[\delta^t\, (\omega \,/.\, x \to sm[[t]]),\ \{t, 1, 20\}\right] + Sum\left[\delta^t\, (\omega \,/.\, x \to sopt[[t]]),\ \{t, 21, 50\}\right]$

Out[126]= 2.94275×10^9

10. To Privatize or Not To Privatize

The following figure shows the welfare differential between the choice of “not privatize” and the choice of “privatize” as λ varies from 0 t0 1. As can bee seen from the figure, the discounted welfare is higher under the “not privatize” choice than under the “privatize” choice for all $\lambda \in [0, 1]$. The monopoly price has a considerably negative impact on social welfare.

In[127]:=
```
Plot[Ωopt - Ωm, {λ, 0, 1}, AxesLabel → {"λ", "Ω*-Ωm"}]
```

Out[127]=