

The influence of regulation and the operational environment on Chinese urban water utilities

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Acknowledgements

We are thankful to Sanford Berg for his advice and suggestions. We also thank Teng Huang for helping us collect the data. Financial support from the Office of Social Sciences and Humanities and the China Center for Special Economic Zone Research at the Shenzhen University in China is also gratefully acknowledged. All remaining errors are our own.

Abstract

China is currently facing water scarcity issues, which can partially be relieved with improvements in efficiency in its urban water supply sector. Using a manually collected utility-level dataset for 2009-13, we examine the regulatory context and performance of Chinese urban water utilities, taking into account their operational environment. Our main findings are that: (1) an increase in the number of non-technical staff does not increase output levels, while an increase in the number of technical staff, length of pipe or electricity usage can increase output; (2) customer density and non-household user rates are associated with lower levels of inefficiency (or higher levels of measured efficiency), while outsourcing staff rate, non-revenue water rate, and average piped water pressure do not significantly affect efficiency. These results suggest that Chinese urban water utilities can be improved through performance-based regulation and incentives that take into account the operational environment of utilities.

Keywords Chinese water utilities, Stochastic frontier analysis, Operational environment, regulation, performance.

JEL Codes L51, L95, L980

1. Introduction

China is currently facing several obstacles in its water supply sector. Years of fast paced industrial growth have led to an increase in standard of living for the population, but the rapid pace of urbanization and industrialization has also been accompanied by over-exploitation and heavy pollution of water sources, reducing water resource availability. The average per capita endowment of water in China is approximately 2000 m³ annually, compared to a global average of about 6200 m³ (World Bank 2012). By 2011, China's urban population had reached more than 50% of the total population, but 400 out of 669 cities faced water shortages and 108 had severe water shortage problems. This translates to an urban population of 160 million that is affected by water shortages (Xinhua net 2015).

China's water shortage problems are so substantial compared to its natural endowment, that they cannot be managed solely through the exploitation of new sources (Liu and Speed 2009). Several supply and demand side approaches, such as inter-basin transfers, desalinization, and waste water reclamation, and conservation, can be used to address water scarcity and pollution in the long term (Cheng and Hu 2012). A cheaper, more immediate, and complementary solution consists of increasing production efficiency at the water utility level. This is especially necessary given how urbanization and living standards are expected to continue to increase in the coming years. For this reason, identifying characteristics of the Chinese water utility sector that are associated with increases (or decreases) in efficiency is of vital importance. The Chinese government's 11th Five-Year Plan for Water Resources Development includes several strategic shifts toward policy implementation, which include improving water use efficiency and benefits as one of its key action areas (Jiang 2009). To our knowledge this is the first paper to quantitatively evaluate urban water utility performance in China. There are, however, papers

evaluating water resource use and water privatization in China. Ma et al. (2016) study water resource utilization efficiency using China's water resources as an output and factors such as economic growth and technological progress as inputs. Our paper differs from Ma et al. (2016) in that we focus on urban water utilities using micro-level data at the firm's operational level rather than looking at the entire water resource using provincial economic indicators. Both of these approaches are complementary and should be taken together to give us a better picture of China's water situation. Jiang and Zheng (2014) develop 12 indicators to assess utility performance in response to private sector participation in the Chinese water sector, but they consider fewer environmental factors in their analysis of utility performance and do not focus on production efficiency.

The regulatory environment of a water utility consists of the set of rules and regulations governing the sector. The regulatory environment constitutes an important element of governance and typically includes oversight of factors such as pricing and subsidies, employment, quality, the environment, and investments. In our paper, we show that data driven efficiency studies can give us clues as to how Chinese policy-makers can focus their efforts on addressing water scarcity, taking into account the operational environment of utilities. These types of results can be used to create incentive frameworks for utility firms.

2. Background: Chinese Water Utility Sector

2.1 Institutional Characteristics

China's urban water services are mainly provided by water supply companies. Most urban water utilities are state owned, but there is some private participation. In 2010, China had average water coverage of 90.3% of the urban population; 15 out of 34 provincial-level

administrative divisions had coverage above this average (China's Urban Water Supply Bulletin 2012).

Water prices in China only cover the utilities' operational costs, and are far from covering investment and wastewater treatment costs (Yin et al, 2008). Underpricing in China's water sector is one of the major causes for allocative inefficiency (poor water use efficiency, World Bank 2007). Water is sold below cost in many areas, which creates strong disincentives for water conservation. In addition, utilities may lack the cash flows for appropriate network maintenance, rehabilitation, and replacement. Such managerial behavior shifts cost burdens to future generations. For example, in Xi'an, households pay 1.6 yuan/m³ while the full cost is 5 yuan/m³ (OECD 2007). The full cost estimate does not include the full opportunity cost of the water itself, as aquifers, groundwater and other water sources are depleted—raising costs in future years. According to Jiang (2009) current household expenditures for water in China account for roughly 1.2% of disposable income, compared to 4% in developed countries. For this reason, current reform efforts are centered on changing pricing mechanisms so that they better align with full cost recovery (Zhong and Mol 2010), but progress raising water prices has been slow because of concerns about access to water being a human right (Jiang 2009), concerns about limiting access for the poor, and concerns about negative impacts on the local economies and development (Lee 2006)¹. Low water prices are expected to lead to deferred maintenance, poor infrastructure, and slow rates of expansion and remediation.

Following the pace of urbanization and industrialization, China's urban water billing system has been upgraded from in-person to automatic billing. Water bills, which are determined by each user's water meter data, are charged directly to customers' bank accounts. Under strict

¹ Nevertheless, there have been examples of water prices being raised in urban areas such as Beijing (Lee 2006).

government regulations, this automatic billing system and low water prices contribute to a relatively high urban water billed (and collections) rate in China.

It should be noted that water utilities did not become as market-oriented as other industries during the Chinese economic reform, leading to regulated low prices and government intervention. Urban water utilities highly depend on subsidies from the national and local governments to cover their costs. Their motivations to improve efficiency are not driven by profit margins, but depend on governmental administration and supervision—where local decision-makers have relatively short time-horizons. China's local water utilities have traditionally been government-ran enterprises without full cost recovery mechanisms. The major source of investment and maintenance over the years consisted of fiscal transfers unrelated to utility performance; these transfers provided little incentive for the utility managers to implement cost containment measures. Private sector involvement to try and alleviate this problem began in 1992 with the entry of Sino-French Water (Wang, Wu, and Zheng, 2011) and was formally allowed in a more institutionalized manner in 2002 (Jiang and Zheng, 2014). Privatization has taken several forms, including Build-Operate Transfer, Build-Transfer, Transfer-Operate-Transfer, Build-Transfer-Operate, equity, property rights transfer, joint ventures, and other Public Private Partnership models (Wang, Wu and Zheng 2011).

2.2. Regulatory and Operational Environment

Water administration is the responsibility of the Ministry of Water Resources, a Chinese government department that was founded in 1949. Its main functions include: providing draft legislation, promulgating water administrative rules and regulations, planning national water investment and fiscal subsidies, and supervising local governments' activities in the water sector. Due to the complexity of local natural resources (hydrology, topology, distance from sources,

and environmental/ecological conditions) and the economic situation (especially industry mix and income levels), the Ministry of Water Resources is not directly involved with the local water administration, and instead assigns the duty of water production and delivery to local governments. However, at the city level, water administration involves multiple departments, including the Environmental Department, the Commerce Department and the Housing Department.

The current method for managing water stems from the 1988 Water Law, which was passed during China's planned-to-market economy transition (Liang, 2005). Today, local-level institutions are under the authority of both central authorities and local (municipal) governments. Laws and policies are directed by the central government, with some negotiation between local and central authorities (Speed 2009). This has led to some ambiguities over system ownership and maintenance responsibilities (Cheng and Hu' 2012). The Water Law was amended in 2002 with the goal of addressing some of the earlier law's shortcomings. One of the four main topics included in the new Water Law is water use efficiency and conservation (People's Congress 2002). Lee (2006) contends that competition and conflicts of interest among various government agencies can occur, and that one of the main problems in the regulatory arena stems from fragmented policy-making and implementation. Some areas of China have successfully addressed this issue by adopting integrated water resource management, with the Shenzhen Water Authority leading the way in 1993 (Cheng and Hu 2012).

The main policy successes cited from recent reform are: the inclusion of environmental aspects (both in the government's Five Year Plan and in specific environmental impact assessments), the establishment of integrated water bureaus, and substantial improvements in water sanitation processes.

The legal framework behind water tariff definitions, collection, and administration is under the State Council's administrative regulations. These regulations operate in conjunction with provincial and local rules and regulations (which are the responsibility of provincial governments). Water tariffs are set at the prefecture level and volumetric water use charges are slowly being introduced in urban areas (Nitikin et al, 2012). The State Council's administrative regulations fall under national laws which are the responsibility of the National People's Congress. The National People's Congress' authority stems from the Constitution (Liu and Speed, 2009).

There are currently no mechanisms in place to incentivize performance enhancing measures at the utility level². A possible future avenue for the Chinese urban water utility system to increase efficiency could be the introduction of performance-based regulation (PBR). PBR provides utilities with strong incentives to reduce costs through rate-setting mechanisms that link rewards to desired targets by setting rates according to external indices (Body of Knowledge on Infrastructure Regulation, www.bodyofknowledge.org). Chinese water data are available at the province and city level, but is very limited at the utility level. This lack of information limits the potential for detailed performance evaluations of city water utilities. Implementing PBR requires an understanding of historic performance, the determination of areas where improvement is possible, and the collection of appropriate information. The Chinese National Government and local governments do not currently have a scientific and unified evaluation system in place for examining the performance of water utilities. For this reason, the government and regulators are unable to steer utilities in a direction leading to performance improvements, despite a general recognition that changes are needed. One such change would involve the implementation of

² Mugisha (2007) provides examples on how incentives have been applied to water utilities in Uganda.

requirements for the collection, authentication, and sharing of information; this would enhance performance analyses, leading to realistic targets and improved incentive mechanisms.

3. Water Efficiency Literature Incorporating Environmental Variables

Ma et al. (2016) study water utilization efficiency in China. They focus on water as a resource which is a more macro-level use of water than our water utility-level study. The authors use sewerage discharge and provincial GDP as output and economic growth, industrial structure, technological progress, government influence, economic openness, water endowment, and water prices as inputs. The unit of study is the province and their main findings suggest that (1) regions with higher economic growth are associated with better water use efficiency, (2) areas with heavy agricultural use have lower utilization efficiency, (3) technological progress is associated with better water use efficiency. They also find that prices do not seem to be related to resource utilization efficiency. This is expected given how prices are not cost-reflective in China. The main difference between our papers is on the focus: Ma et al. (2016) look at the entire water endowment resource and see how efficiently water as a resource is used in China's provinces. Our study looks at how much the portion of that water that is being used by utility firms in urban areas is efficiently delivered to its final customers (households, commercial, industry, and government).

Most water utility efficiency studies focus on examining the following objectives: scale, scope, and density of utilities, type of ownership (private versus public), regulation, and benchmarking. Berg and Marques (2011) provide a literature survey of 190 quantitative studies of water utilities. Most studies examine water utilities in Europe and North America, and use cost or production functions. Benchmarking techniques are utilized in most of these studies.

In recent years, several benchmarking studies have highlighted the importance of incorporating environmental variables that are expected to influence performance. These studies measure technical efficiency using cost or production functions, and either Data Envelopment Analysis (DEA) or Stochastic Frontier Analysis (SFA) techniques. DEA, a non-parametric method, uses linear programming to determine the efficiency of firms. Water utility production function DEA studies generally employ an input orientation, in which inputs are minimized for a given output level. SFA, a parametric method, uses statistical analysis to examine efficiency. Unlike ordinary least squares methods, SFA models assume that the error term is composed of both noise and productive inefficiency. There are advantages and disadvantages to both DEA and SFA and neither method is strictly preferred over the other.³

Recent studies have been more comprehensive—incorporating factors beyond management’s control. Carvahlo and Marques study the efficiency of Portuguese water utility companies using DEA techniques (Carvalho and Marques 2011) and Bayesian SFA (Carvahlo and Marques 2016) . . Environmental variables are exogenous variables that affect the performance of water utilities. The authors argue that excluding environmental variables in efficiency studies could result in biased estimates, particularly if the variables heavily influence the water production process. In a similar study, Marques et al (2014) examine the influence of institutional and environmental factors on Japanese water utilities using a DEA production function. They include several exogenous environmental variables such as outsourcing, leakage, and peak factor. Picazo-Tadeo et al (2009) study Spanish water utilities with a focus on differences between private and public firms. Byrnes et al (2010) examine the efficiency of 52 water utilities over a 4 year period in

³ The main advantage of SFA compared to DEA is that it accounts for statistical noise and allows for statistical inference. The main advantage of DEA compared to SFA is that it does not require the imposition of a functional form and can incorporate multiple outputs relatively easily (Coelli et al. 2005).

Australia, using a production function DEA model that incorporates exogenous environmental variables such as residential consumption (capturing customer mix) and customer density. Renzetti and Dupont (2009) study the influence of environmental variables such as population density in a cross-section of Canadian water utilities. Phillips (2013) examines the efficiency of water utility firms in Japan, using a SFA production function. This study's environmental variables include customer density, outsourcing, and intake water volume. Mugisha (2014) examines technical efficiency effects in Uganda's water utilities for the 2002-2010 period and finds that financial incentives and increased service coverage improve efficiency, while targets such as the reduction of non-revenue water reduce it. Buafua (2015) studies technical efficiency of urban utilities in sub-Saharan Africa, and finds that regulating operators using performance contracts and private sector participation in management leads to higher technical efficiency. Although the literature examining water efficiency in developed countries is extensive, data driven efficiency studies of Chinese water utilities are limited, utilizing data prior to 2009. To our knowledge, there are only three empirical economic studies in this field. Jiang and Zheng (2014) study the impact of private sector participation (PSP) on Chinese water utility performance, using a panel of 208 utilities from 1998 to 2007. They find that PSP is weakly associated with increased sales revenue, reduced number of workers, and increases in total factor productivity (TFP)⁴. The authors attribute the increased efficiency to employment downsizing and decreased managerial expenses, rather than tariff increases. Wang, Wu, and Zheng (2011) also study the impact of private sector participation in China's urban water system, using panel data from 35 major cities in the 1998-2008 period. They find that introducing private sector participation is correlated with improvements in integrated production capacity and water

⁴ Most of these results are not statistically significant at conventional levels.

coverage rates. Regarding performance, they find that private participation by foreign companies increases performance. Neither of these studies are benchmarking studies; they do not focus on the efficiency of China's water utilities or the role of environmental factors.

Browder et al (2007) provide a very general overview of the performance of Chinese urban water utilities, which, on average, perform at a level similar to other middle income countries. The authors find that Chinese urban water utilities have very unequal levels of performance, suggesting that rapid improvements could be achieved if low performing utilities can somehow learn from well-performing utilities. The Browder et al (2007) study provides a very general performance assessment, examining one variable at a time and providing summary statistics.

There are very few studies of Chinese urban water supply performance that use statistical methods, mainly due to data availability issues. China's Urban Water Association, a nonprofit national organization, has started to collect performance data at the utility level. Although only the main and large-scale city utilities report their performance, the number of self-reporting utilities increases year by year. Performance indicators include variables such as leakage, staff composition, revenue collection and pricing, which can provide a rough picture of the performance of Chinese city water utilities. This enables us to evaluate China's urban water utility performance, incorporating environmental factors to address the reasons for inefficiency in the sector.

4. Model

We use a SFA model to examine the performance and operational variables influencing Chinese water utility firms, following Battese and Coelli (1995). SFA models were simultaneously introduced by Aigner et al (1977) and Meeusen and Van den Broeck (1977). SFA models allow for the examination of a firm's inefficiency, by including both noise and an

additional component representing productive inefficiency in the model's error term. Battese and Coelli's (1995) SFA model specification allows for the incorporation of environmental variables, which can be used to examine factors influencing technical efficiency. This is done through a one-step approach in which both the stochastic and efficiency components are estimated simultaneously (Schmidt and Wang 2002). Efficiency is defined as the output of a given firm relative to the output that could be produced by a fully efficient firm using the same input vector; water utility's efficiency is affected by its regulation and institutional environment.

4.1 Data description

We manually collected data from the Chinese Yearbook of Urban Water Supply from 2010 to 2014. The yearbook publishes performance data at three different levels: province, city and utility. We use a pooled unbalanced panel sample consisting of 59 city utilities (140 observations) between 2009 and 2013. The performance data is self-reported by city utilities and collected by China's Urban Water Association. The model considers one output, four inputs and five environmental (operational) variables (also known as the inefficiency factors of the model).

4.2. Production Function Model Description

Consider a Cobb Douglas stochastic frontier production function one-step inefficiency effects model as specified by Battese and Coelli (1995) for panel data:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln(K_{it}) + \beta_2 \ln(LT_{it}) + \beta_3 \ln(LNT_{it}) + \beta_4 \ln(E_{it}) + V_{it} - U_{it} \quad (1)$$

where β is a vector of unknown parameters to be estimated; $\ln Y_{it}$ is the natural logarithm (with base e) of total delivered water volume in a year in 10,000m³(output), for the i^{th} utility in year t where $i = 1, \dots, I$ and $t = 1, \dots, T$; inputs are defined as: Capital (K_{it}), proxied as length of pipes (in 1000m); labor (LT_{it} and LNT_{it}) measured by the number of technical staff and non-technical

staff, respectively; and energy (E_{it}), hourly electricity usage (100,000 kwh)⁵. V_{it} is an error term picking up what the model cannot explain (noise); and U_{it} is a technical inefficiency term, consisting of non-negative random variables. The U_{it} term is subtracted because inefficiency results in less output. V_{it} is assumed to be independent and identically distributed with $N(0, \sigma^2)$ random errors, which are distributed independently from U_{it} . U_{it} is assumed to be independently distributed, and obtained by truncation at zero of the normal distribution with mean $Z_{it}\sigma$ and variance σ^2 , where Z_{it} is a vector of explanatory variables associated with technical inefficiency of production for utility firms over time.

The relationship between U_{it} and Z_{it} is defined by the following technical inefficiency effects specification:

$$U_{it} = \delta_0 + \delta_1(rout_{it}) + \delta_2(cusden_{it}) + \delta_3(nonrevr_{it}) + \delta_4(nonhhdr_{it}) + \delta_5(avepress_{it}) + W_{it} \quad (2)$$

where δ is a unknown vector of coefficients to be estimated; W_{it} is a random variable defined by the truncation of the normal distribution with mean 0 and variance σ^2 (Coelli 1996; Battese and Coelli 1995). The environmental variables that are expected to influence performance are defined as: Outsourcing ratio ($rout_{it}$), measured by the ratio of number of staff based on temporary contracts to the number of total staff (%); Customer density ($cusden_{it}$), defined by the number of customers per length pipe (persons/1,000 m); Nonrevenue water rate ($nonrevr_{it}$), defined by the ratio of volume of nonrevenue water to the number of total delivered water volume (%); Non-household user rate ($nonhhdr$), defined by the ratio of the number of non-household users to the number of total water users; and average piped water pressure ($avepress_{it}$) (1 million pa). The use of these variables in the inefficiency effects model allows us to

⁵ Electricity is an input for pumping and distributing water. We lack data on chemicals for water treatment and distance from water source.

incorporate variables that affect the efficiency of water utilities in China. Summary statistics for variables in the stochastic frontier production function are given in Table 1.

Table 1: Summary statistics

Variable	Sample mean	Standard deviation	Min. value	Max. value
Delivered water volume	12705.60	22086.08	182.5	91991
Length of pipes	1212.06	1897.02	3.9	10840
Technical staff	135.51	229.21	3	1896
Non technical staff	549.34	685.69	19	4709
Electricity usage	2962.02	4506.77	8.1	32982
Outsourcing ratio	0.08	0.14	0	1.00
Customer density	0.08	0.07	0.01	0.51
Non revenue water rate	0.19	0.13	0.00	1
Non household user rate	0.51	0.19	0.07	1
Average piped water pressure	0.32	0.27	0.15	3.2

N= 140 observations.

The model is estimated using the maximum likelihood method. The parameters in the stochastic production frontier (equation 1) and the technical inefficiency effects (equation 2) are estimated simultaneously. The technical efficiency of production obtained for the i^{th} utility firm at year t , is always between 0 and 1 measuring the output of the i^{th} utility firm relative to the output that could be produced by a fully efficient utility firm using the same input vector. It is defined by equation 3 below and automatically calculated by Coelli's (1998) *FRONTIER* version 4.1 software.

$$TE_{it} = \exp(-U_{it}) \quad (3)$$

By definition, firms with a technical efficiency score closer to 1 are more efficient.

In stochastic frontier models, the composite error is given by $V_{it} - U_{it}$. If the U_{it} part of the equation is not necessary, OLS would provide consistent estimates. In order to test for whether or not stochastic frontier analysis is needed, a value for gamma is calculated by Battese and Coelli's (1995) model, where gamma is defined as $\gamma = \sigma_u^2 / \sigma_v^2$ and ranges from 0 to 1. A gamma value of 0 indicates that OLS provides consistent estimates and there is no need for an

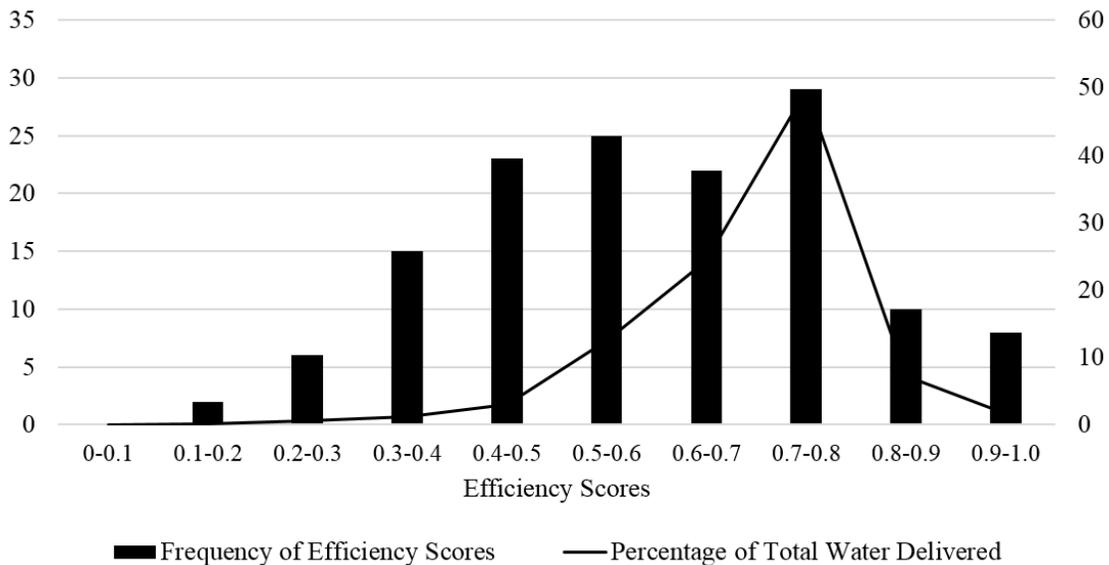
inefficiency component in the error term. Our estimate for gamma is 0.45 (t-ratio 2.94). Since gamma is statistically significant at the 1% level, at least some variation of the composite error term is due to inefficiency, implying that SFA is preferable to OLS in this context.

5. Empirical Model

5.1. Results

The efficiency of Chinese firms in our sample ranged from 0.12 (least efficient) to 1.00 (most efficient). This means that the most inefficient firm could reduce usage of inputs by 88%. The frequency distribution of technical efficiency scores can be seen in Figure 1. Over 80% of the firms have an efficiency score of less than 0.70. Another way of expressing the variation is that XX % of the water delivered is from utilities with scores of less than 0.70 (see Figure 1). These results are consistent with previous work suggesting that performance of Chinese water utilities is unevenly distributed (Browder et al 2007); the results indicate that there are opportunities for weak performers to learn from strong performers. The results for the production function are presented in Table 2, while the results for the inefficiency effects are presented in Table 3.

Figure 1: The frequency distribution of technical efficiency scores (all years in sample).



Note: A firm with an efficiency score equal to one is fully efficient. The left hand side axis shows the distribution of technical efficiency scores (%). The right hand side y-axis shows the percentage of water delivered for utilities with corresponding efficiency scores (%).

Table 2: Production function

Variable	Coefficient	t-ratio	standard error
Intercept (β_0)	2.3219***	4.97	0.4667
Ln length of pipes (β_1)	0.5636***	6.61	0.0853
Ln technical staff (β_2)	0.2262***	2.99	0.0755
Ln non-technical staff (β_3)	0.1237	1.42	0.0870
Ln electricity usage (β_4)	0.1933***	2.95	0.0655

N= 140, T=5, cross sections = 59. Unbalanced panel. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table 3: Inefficiency effects

Variable	Coefficient	t-ratio	standard error
Intercept (δ_0)	1.9180***	5.57	0.3444
Outsourcing ratio (δ_1)	-1.0644	-1.18	0.9022
Customer density (δ_2)	-6.0243**	-2.57	2.3400
Non-revenue water rate (δ_3)	-0.2107	-0.24	0.8615
Non-household user rate (δ_4)	-1.8420***	-3.42	0.5392
Average piped water pressure (δ_5)	0.2330	0.82	0.2831

N= 140, T=5, cross sections = 59. Unbalanced panel. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

All of the input variables are positive, as expected, implying that increases in inputs lead to increases in output. A 1% increase in technical staff, for example, is associated with a 0.22% increase in total delivered water volume (see Table 2). All inputs, with the exception of non-technical staff are statistically significant at conventional levels. The non-statistically significant result for the non-technical staff variable may be related to the issue of overstaffing. According to Nitikin et al (2012), overstaffing is a well-known problem for the public water sector in China. This problem is not currently being addressed aggressively due to concerns about the welfare implications of laying off the excess labor force. This result is also consistent with how employment downsizing is seen as one of the major benefits of utilities that have been privatized, as noted by Jiang and Zheng (2014).

As mentioned earlier, given China's current strategic shift towards policy implementation that includes improvements in water use efficiency at the water utility level as one of its key action plans, it is useful to identify environmental factors that influence performance.

The customer density variable has a negative coefficient that is statistically significant at the 1% level (see Table 3). According to our results, water utilities with greater customer density tend to be less inefficient (more efficient). This result is expected because, assuming a fixed network length, adding more customers translates into higher levels of output, given fixed input levels. In China, water scarcity and pollution are problematic in both rural and urban areas.

Our customer density finding is consistent with the water utility efficiency literature, which supports the existence of economies of density in Italy and Spain (Antoniolli and Filippini 2001; Picazo-Tadeo et al 2009⁶). For Asian countries, the only studies we are aware of that examine economies of density are of Japanese water utilities, presumably due to data availability. Mizutani and Urakami (2001) examine network length in the context of a Seemingly Unrelated Regression (SUR) cost model, and show economies of network density for water utilities in Japan. Phillips (2013) also studies Japanese water utilities and finds that water utilities with greater customer density are associated with less inefficiency. Thus, our results are consistent with recent studies of Asian water utilities.

The non-household rate variable has a negative coefficient (see Table 3). This implies that water utilities with a larger customer base of non-households (i.e., more industrial and commercial customers) tend to be less inefficient, suggesting that there are efficiencies involved in serving industry, businesses, and government when compared to residential customers. The

⁶Antoniolli and Filippini (2001) use a cost function while Picazo-Tadeo et al (2009) use a production function to study density.

influence in water efficiency of residential and non-residential customers has been heavily studied in the performance evaluation literature. Water utilities with more residential customers are expected to have higher costs, which are related to lower efficiency levels⁷. This is expected given how non-residential customers have more predictable patterns of use. This result is consistent with Anwandter and Ozuna (2002) who studied the efficiency of water utilities in Mexico and found that utilities serving a higher proportion of non-residential customers were more efficient. Carvahlo and Marques (2011) found that residential customers in Portugal had a negative influence on performance of water utilities but only up to a certain range. Byrnes et al (2010) found the opposite result, which they attributed to regulations requiring heavier water treatment investment for industrial customers in Australia. According to Browder et al (2007), historically, there have been significant cross-subsidies flowing from industrial and commercial customers to residential users in China. These cross-subsidies are a remnant of the country's planned economy where state owned enterprises were expected to subsidize basic domestic services. We do not have data on subsidies, but expect utilities with more non-household customers to be more efficient given historical reasons that required them to cover costs of serving residential customers.

The outsourcing ratio, non-revenue water rate, and average piped water pressure variables are not statistically significant at conventional levels, implying that there is no effect on inefficiency for the data in our sample (see Table 3). In China, the employment contract between outsourcing and internal staff is usually quite different from other countries: outsourcing staff have obvious

⁷ This variable influences costs rather than efficiency. Even though these are not the same concept, this variable has been included both in this study and in other production function studies in the literature because excluding it is expected to result in a biased analysis since it is an influential environmental variable. Ignoring this variable is expected to result in unfair comparisons of efficiency where firms with higher proportions of residential customers would receive lower efficiency scores (Carvahlo and Marques 2011).

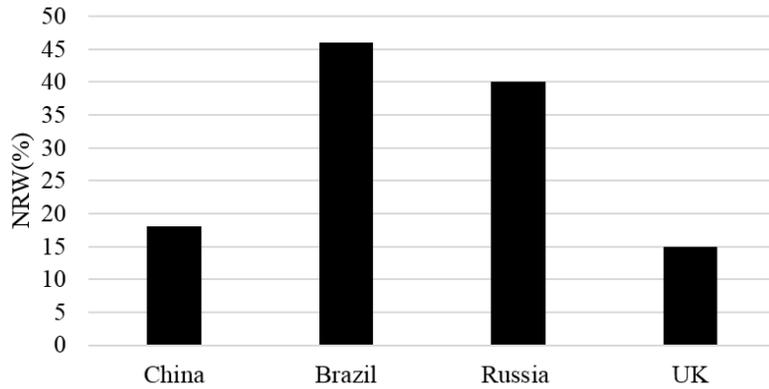
disadvantages in terms of insurance, pensions, and salary. Additionally, outsourcing staff's contracts are temporary, while internal staff's contracts are permanent. As a result, on the one hand, outsourcing staff have less incentives to work hard given their low income packages and short-term employment contracts; on the other hand, internal staff also have less incentives to improve their performance because poor performance rarely results in layoffs, given their permanent contracts. This negative effect of outsourcing ratio on production efficiency is (presumably) countervailed by the negative effect of the internal staff ratio, so our results show that the outsourcing ratio has insignificant effects on inefficiency.

Regarding non-revenue water, compared to other middle income countries, such as Russia and Brazil (see Figure 2), China has more compact systems with 1,100 people per kilometer of distribution network on average (Browder et al 2007). For this reason, non-revenue water percentages are much lower than in other countries which may help explain our findings for this variable⁸. In addition, Chinese cities have high billing and collection rates due to their automatic

⁸ Note that leakage per kilometer can still be high, so further research in this area is needed to see whether performance improvements can be achieved by repairing or replacing pipes.

billing systems—reducing unpaid bills. Figure 2 compares non-revenue water percentages in China to other countries.

Figure 2 China's NRW (%) compared to other countries.



Note: Year 2005-2006. Source: Browder et al 2007.

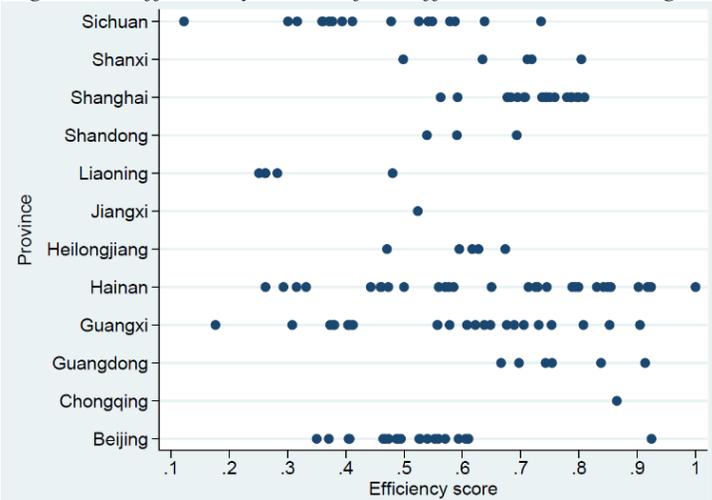
5.2. Institutional Discussion and Policy Implications

The main purpose of this section is to utilize the efficiency scores derived for each firm in our model from section 5.1 to study regional and labor relationships that exist in water utility firms more closely. Given the lack of utility-level performance data, most studies of Chinese urban water institutions are qualitative. To fill this research gap, our empirical efficiency study can shed a light on how institutional characteristics relate to Chinese urban water efficiency quantitatively. The relationship of the following institutional characteristics to the efficiency of Chinese urban water utilities is analyzed in this section: region and ratio of number of staff to number of customers. Efficiency scores range from 0 to 1, where 1 is a fully efficient utility firm. These relationships are presented in Figures 3 and 4.

China exercises jurisdiction over 22 provinces, 5 autonomous regions, 4 direct-controlled municipalities (Beijing, Tianjin, Shanghai and Chongqing), and 2 mostly self-governing special administrative regions (Hong Kong and Macau). This study involves the main urban utilities of 9 provinces and 3 direct-controlled municipalities. It was expected that poor raw water conditions

would require more input to produce the same levels of output. The main rivers that flow through China include the Yangtze River, the Pearl River, the Yellow River, the Huai River, the Hai River, the Liao River and the Songhua River. Among them, the raw waters from the Yangtze River and the Pearl River are of high-quality, while the raw water from the Huai River and the Hai River are of low-quality (China’s Water Resource Bulletin 2013). Figure 3 shows that urban water utilities in Guangdong (along the Pearl River) and Shanghai (along the Yangtze River) have relatively high efficiency scores, while urban water utilities in Liaoning (along the Liao River) have relatively low efficiency scores. In addition, Guangdong and Shanghai are the most developed regions in China, and generally show high efficiency in operation and production, regardless of the industry.

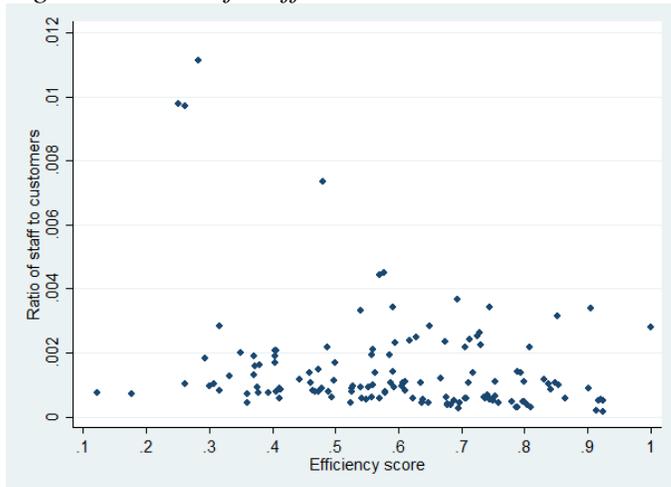
Figure 3: Efficiency Scores for different Chinese Regions



As Figure 4 indicates, the ratio of number of staff to number of customers shows a weak negative relationship with efficiency scores. A few utilities with low efficiency scores show high ratio of staff to customers. The labor supply of these utilities has a high percentage of nontechnical staff. According to our SFA result, as an input variable, the number of nontechnical staff has no significant effect on increasing output. Thus, utilities with low efficiency do not significantly show that they need more labor input to supply water customers. This result is

consistent with privatization studies suggesting that gains from privatization seem to stem from reductions in the labor force.

Figure 4: Ratio of Staff to Customers and its relationship with efficiency scores.



Note: The ratio of staff to consumers is 0.031 for the Hegang utility in 2009, so this observation is considered an outlier and dropped from the figure.

5.3. Alternative Models

Efficiency in producing outputs using inputs can also be measured using an SFA model that does not include controls for the operational environment in the inefficiency term and DEA. We tested our model against a different SFA model to check for the sensitivity of our results for the production function to our model specification. It is important to note, however, that our additional specification does not account for the operational environment and thus, does not make use of the information provided by the variables in Table 3. Table 4 includes the main results from our new production function model, the time invariant SFA model (which excludes operational variables). If we compare this model to the results from Table 2, we can see that once again, all inputs are positively related to the output. The main difference is that non-technical staff is now statistically significant.

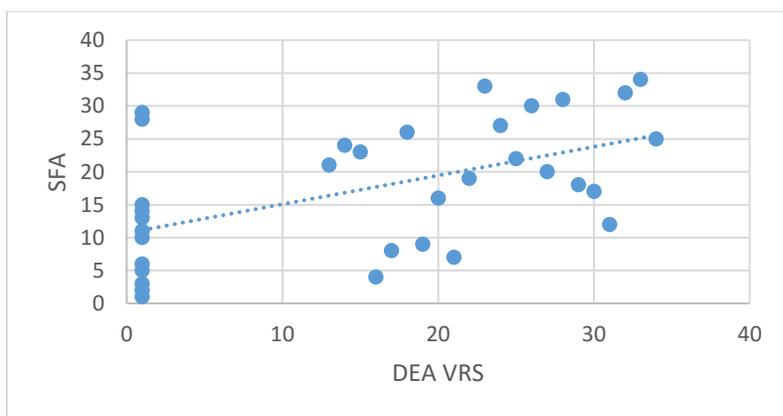
Table 4: Production function: Time invariant SFA model

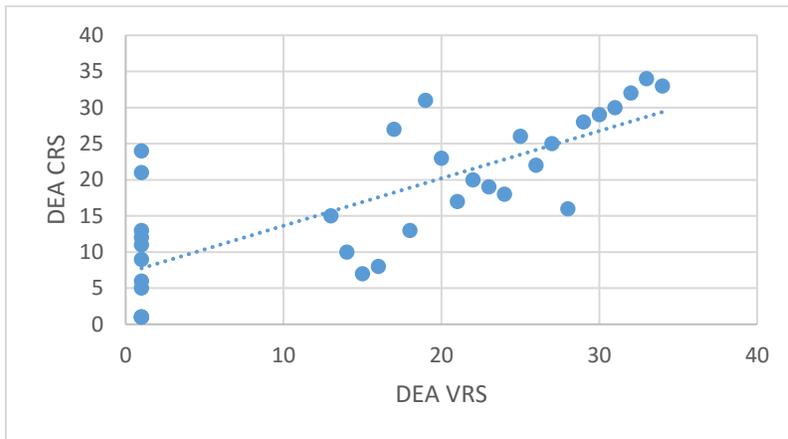
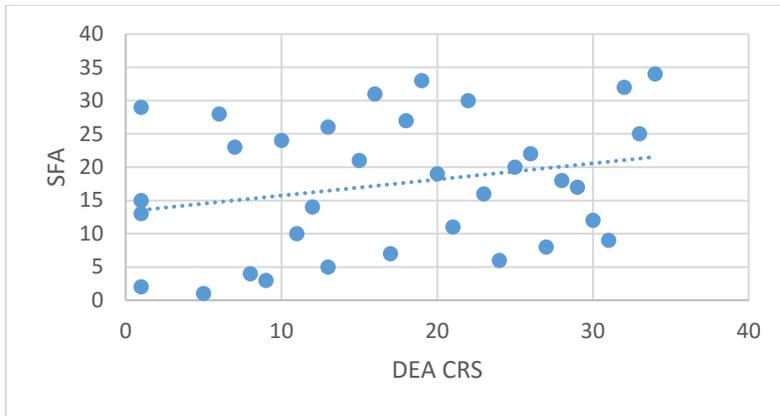
Variable	Coefficient	t-ratio	standard error
Intercept (β_0)	1.0272***	3.41	0.3015
Ln length of pipes (β_1)	0.5959***	8.38	0.0711
Ln technical staff (β_2)	0.1520**	2.25	0.0676
Ln non-technical staff (β_3)	0.2488***	3.84	0.0648
Ln electricity usage (β_4)	0.2032***	3.52	0.0578

N= 144, T=5, cross sections = 59. Unbalanced panel. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. Note: N is higher because less observations were dropped from the sample when operational variables were excluded.

Another method commonly used for modeling efficiency is DEA. DEA, a non-parametric method and SFA are not directly comparable. DEA does not provide parameters but it does provide efficiency scores. We ranked the firms in our sample for year 2012 (the year with the most observations) using the efficiency scores obtained from each model and created scatter plots comparing the rankings of each new model to the ranking provided by our preferred specification presented in section 5.1 and to each other, as shown in Figure 5. We added a trend line which shows a positive relationship between the rankings, which is expected. The graphs suggest that even though DEA and SFA are completely different models that cannot be directly compared to each other, there is some agreement as to which firms are efficient for our Chinese dataset (if the rankings were very closely related, the data would be at the 45 degree line).

Figure 5: Scatter plot of rankings between DEA VRS, DEA CRS, and SFA models.





6. Concluding Observations

In this study, we manually collected a recently released and unique firm-level dataset covering 59 utilities from the 2009 to 2013 period to study the performance of Chinese urban water utilities, incorporating their operational environment. The estimation shows that the efficiency of Chinese firms in our sample ranges from 0.12 (least efficient) to 1.00 (most efficient). This result is consistent with the literature suggesting that performance of Chinese water utilities is unevenly distributed (Browder et al 2007). Since a high level of inefficiency exists, there is an opportunity to improve Chinese urban water utilities by providing a regulatory framework that incorporates performance benchmarking into its incentives.

We also find that an increase in the number of non-technical staff does not raise the output level, measured by delivered water volume per year, while an increase in the number of other inputs (technical staff, length of pipe and electricity usage) can improve the output levels. According to our results, better institutional control in the form of reducing the number of non-technical staff can save operational costs without reducing the output level, which would be beneficial for the financial sustainability of Chinese urban water utilities. In addition, we find that environmental factors, such as customer density and the non-household user rate, are associated with lower levels of inefficiency, which is consistent with the literature on piped water networks and water user behavior. At the same time, the outsourcing staff rate, non-revenue water rate, and average piped water pressure variables were not found to be significantly related to efficiency. These results are presumably driven by incentives provided by employment contracts, China's current billing and pricing system, and its diverse landscape/geography, respectively.

To the best of our knowledge, this is the first quantitative study of the influence of operational characteristics and institutional characteristics of urban water utilities in China. China's economic development has achieved great success thanks to rapid urbanization, but its water scarcity problems could obstruct further development. Water issues have driven several recent policy changes and are expected to drive even more changes in the future. One such policy change could come from the way in which urban water utility firms are regulated. If China moves to regulation that takes into account performance, it would be important to consider its operational environment, so as to make fair comparisons among utilities and not punish managers for what is beyond their control⁹. Moreover, this regulatory framework could increase

⁹ For instance, variables such as customer density and non-household user rate are important factors that need to be included in models but that are not under managerial control.

China's policy-makers' awareness of possible changes to the operational and institutional environment of water utilities that can be made to promote utilities' performance improvements.

A recent set of studies by the OECD identify twelve principles of water governance that warrant attention from policy-makers around the globe (OECD, 2015). The principles address problems characterizing many nations; those problems include lack of policy coherence, inadequate monitoring and evaluation at the water basin scale, unclear roles and responsibilities, absence of financial sustainability (and consistency in funding investments), and a lack of skilled professionals for developing incentives promoting strong performance. Basically, regulatory frameworks need to be strengthened in most nations—including greater attention to coordination within the data collection and analysis process.

Our empirical results underscore the benefits from improved governance processes which could address characteristics such as customer density, customer type, overstaffing, and water prices. A more comprehensive system of data collection and the addition of performance based incentives to China's current regulatory regime could help identify further areas of improvement. This study explores China's urban water sector by depicting a relatively comprehensive, albeit preliminary, picture of the performance of water utilities and providing policy implications to improve their efficiency. The importance of adequate data collection systems and performance-enhancing incentive schemes are highlighted as possible avenues for addressing China's current water scarcity issues.

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