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Charges for Water and Access: What Explains the Differences in West Virginian Municipalities?

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Charges for Water and Access: What Explains the Differences in West Virginian Municipalities?

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Abstract

Applying linear and log-log functional forms plus spatial econometric analyses to a dataset of 125 municipal water utilities, we investigate the determinants of charges for water use and minimum monthly access to water across West Virginia municipalities in 2014. Water charges models are consistent with the theory of water cost determination as water source, debt, and economies of size plus scale influence what household consumers pay for water. Based on model results, groundwater use by utilities lowers water charges and is estimated to save household customers in West Virginia over $3.6 million annually. West Virginia households typically pay far below the OECD standard of 3 to 5% of household income for municipal water, which may explain why socioeconomic factors do not influence minimum charges for access.

Keywords: water charges, social equity, utilities, spatial econometrics
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1 Introduction

Water is a basic resource that is vital to the existence of life. Because of this, provision of potable water is often discussed as a basic human right (UN, 2010). While a renewable resource, the global water cycle implies essentially a fixed water supply (Renzetti, 2012). Increasing demands for water strain the ability of communities to achieve sustainable management. One of the main goals in a sustainable water planning system is providing adequate supplies of clean water for all users at a reasonable cost (Gleick, 1998). According to the World Bank (2015), 99% of Americans have access to an improved water source, however, consumers pay vastly different amounts for the same volume of water. For instance, Walton (2015) provides water price data for 30 major U.S. cities with a range for the same volume of water from \$23.26 (in Fresno, CA) to \$153.78 (in Santa Fe, NM).

Provision of clean and reliable water is a key element of any developed society. Water markets are mostly dominated by monopolists or at least contains monopoly elements (Klein, 2010). The lack of any feasible and realistic competition makes it necessary to have a regulatory mechanism in place to deal with the negative externalities imposed by a monopoly market. In West Virginia, the provision of water services occurs as a regulated monopoly. The West Virginia Public Service Commission (WVPSC) provides oversight for this necessary government function to ensure that consumers have access to safe and reliable water supplies at reasonable rates. Through the WVPSC, municipal utilities operate as monopolies within their communities because of the capital intensive structure of a water utility.

Pricing regulation by the WVPSC is based on the costs faced by water providers. However, when water charges across West Virginia municipalities are examined on the basis of total cost to the customer for 4,500 gallons, a more than five-fold difference is observed (from \$13.26 in Vienna to \$71.89 in Matoaka) (WVPSC, 2014). This range is comparable to that found at a national level even with a much more homogenous climate in West Virginia. Figure 1 demonstrates this variety of charges across West Virginia municipal utilities.

Given these dramatic differences in water charges and a growing concern for the municipal agencies' actions for supplying drinking water (Renzetti, 1999), our main objective in this research is to examine what factors explain the cost differences among municipal water utilities across the state of West Virginia. We use a cost-based approach to determine what factors explain water pricing differences.

In this research, we use the term water charge as the concept to be examined. Price and charge both involve the element of money, but price describes how a consumer must pay to gain an additional unit of product or service, while charge is the total amount paid to acquire a certain quantity of a product or service. In terms of water supply in the United States, water charge is a way to standardize the acquisition of water across a multitude of pricing structures. Water utility pricing structures often include a minimum charge and either fixed or variable unit charges (usually on a per 1,000-gallon basis).

Besides this main objective, we ask another question about whether social equity concerns are linked to minimum charges for access to water provision (independent from the water volume consumption) among water utilities. We will investigate whether minimum charges by utilities account for socioeconomic circumstances within a community or not. Similar to water charges, minimum charges differ across municipal utilities. For example, there are 30 municipalities in West Virginia whose minimum charge to consumers is zero, while the highest minimum charge in our sample is at the municipality of Sistersville where households have $39 per bill as the minimum charge.

V. and Tsitsifli (2014) point out that assessment of minimum charges is not socially fair. Fairness matters to consumers, especially fairness in distribution is a concern in political philosophy. Apart from the income level, all individuals should have access to water. In the scope of fairness literature, consumers need to pay for water based on their ability to pay. This is an issue that we try to address in this study by examining minimum charges where households are obliged to pay a fixed charge per month to have access to water. These charges generate a secure source of revenue for the local water utilities that enable them to cover, for example, water losses in their network.

Finally, we introduce the spatial aspect to models that explain water and minimum access charges. We add geographic variables to investigate the spatial implications of water charges. Commonly, municipal utilities located in the same county or region will have similarities in their primary source of water, topography, cost of living, etc. These similarities among municipalities in a region may have effects on either water charges or minimum charge determinants in a spatial framework.

Thus, this study contributes to the literature in three ways. First, we introduce spatial characteristics to the model to determine the extent to which neighboring municipal utilities influence the municipal water charges. Second, we consider geography and morphology attributes in the water charges model. Lastly, we test to see whether social equity considerations explain minimum access charges to water provision. Previous studies related to the economy of water, introducing data, conceptual and empirical models will be explained respectively. In the last two parts we provide the results and end the research by discussion.

2 Literature Review

Among the studies on water issues include water pricing systems, ownership, regulatory policies specifically on utilities, and social equity. Teresa and Rodriguez-Ferrero (1998) argue that natural hydrological conditions require application of a complex, integrated and highly developed water management and pricing systems. From Susan and Teeples. (1996), who recommend a hedonic cost function for water provided by public versus private, to Bae (2007), who investigates institutional factors influencing the water pricing system, there is a considerable amount of research evaluating water pricing in the U.S. These pricing structures involve different systems of either a uniform block rate, decreasing block rate, increasing block rate, or increasing and declining block rate. There is a clear trend in water conservation policies towards volumetric charging (David and Jeffrey (2006). Katrin and Nauges (2007), Alexandros and Zachariadis (2013), and Bill and Troy (2008) argue that consumers accept practical incentives such as rebates or exchange of high efficiency type appliances more than price increases or water restriction policies, while Mary and Archibald (1998) find that price-based policies are as effective as non-price policies. Kenneth et al. (2014) is an example of investigating a new water rate mechanism (increasing block rate water budgets), which considers household-specific characteristics and environmental conditions in setting a more efficient block rate.

Goldstein Goldstein (1998) argues that potable water is an inexpensive, virtually limit-less resource in many areas of the United States. According to Goldstein, accessibility and availability of the water supply is the reason why water cost is not a substantial concern. After 30 years of changes in availability of water resources, the Goldstein argument of limit-less water supplies in the U.S. is questionable (e.g. Tracy et al. (2015) note examples in the western U.S.). The main recommendation of setting water charges in a way that reflects the full cost of providing water is still accurate and valuable.

Many studies show that the differences in efficiency between public and private sectors are not statistically significant. Renzetti 2004 is an example of research that emphasizes a lack of evidence for differences in performance of public versus private utilities. Teeples 1998 replicate three cost models of water delivery systems to compare ownership efficiency. They find that as specification improves, differences between public and private water supplies reduce to insignificance. This is the same result that Bel 2010. find - there is no empirical evidence that private ownership is more efficient than public ownership utilities. 2012 points out that this result is not surprising because of a wide range of different circumstances in each case study.

Savenije (1998) argues that because a large investment (high fixed cost) is needed to supply water at an economy of scale, water provision is a natural monopoly market. Residential water supply is also considered a natural monopoly (Müller Müller (2015). As Holland (2006) points out, the owner of a water supply system is interested in shrinking the deliveries in order to increase the profit by a higher cost of water provided to customers. Governmental regulation is required to control the monopoly structure of the water market (Pahl-Wostl (2015)).

Barbara and Filippini (2001) estimate a water variable cost function in the regulation of the Italian water industry at the provincial level applying network characteristics. Although the authors did not have access to the data, they recommend the inclusion of geographical and morphological variables in the cost function to achieve a more realistic result. They conclude that the cost of labor, water loss, and service area characteristics are the most influential factors in the water pricing mechanism. Using a stochastic cost frontier approach, Cécile and Reynaud (2005) examine the effects of regulation on the efficiency of water utilities in Wisconsin. The motivation for choosing Wisconsin is that utilities follow different regulatory regimes (e.g. price cap or rate-of-return). The authors find that regulatory regimes affect utilities' efficiency scores.

Bae (2007) separates the influential factors in a water supply cost into four major categories: (1) institutional arrangements and characteristics, (2) government regulations, (3) supply factors and characteristics, and (4) natural environment and local characteristics. The maximum capacity of water production and treatment, water sources, water loss during water production, and pricing rate structures are the explanatory variables that Bae (2007) uses to impose on the model for a sample of 259 utilities across the U.S. He finds that water rate regulations by the public utility commission have a negative effect on water cost. While the author introduces natural environment characteristics, he does so only by including a corresponding variable in the empirical model for LCV index (League of Conservation Voters) to rank the states. High LCV index scores imply higher water cost.

Pahl-Wostl (2015) argues that it is inevitable that one role of government within water management systems is to control for inequality and fairness.

Consumer Utilities Advocacy Centre (2012) contends that social equity was traditionally an important concern in the urban water pricing system, while nowadays policies focus on different aspects such as water efficiency, financial sustainability, and cost recovery. He recommends a two-part tariff: a fixed supply charge and a variable charge. Based on household income or other economic circumstances, the requisite social support policy should be considered in a fixed charge.

Bakker (2001) discusses economic equity versus equalization in water policy. Distinguishing between these two concepts, he explains that according to the equity principle, users should be charged according to their ability to pay. Following Bakker by applying a Cobb-Douglas cost function, García-Valiñas (1983) uses the same equity argument to propose a tariff rate which achieves efficiency, equity, financial aspects and/or public acceptability and transparency. In this function, the author controls for water supplied, labor and capital cost, and the length of the pipeline. In the five European metropolitan cities studied by Bithas (2008), he argues that increasing block rates do not promote social equity and recommends the number of members in each household to be considered in setting water cost. Finally, the Organization for Economic Co-operation and Development recommends that water bills not exceed 3-5% of annual household income (OECD (2003); OECD (2010)).

3 Models

As motivated by Bae,2007 the general form of a model that explains water charges to customers from a municipal water utility can be written as:

$$WC_{it} = f(Q_{it}, In_{it}, En_{it}, Ge_{it}) \tag{1}$$

where (WC) is the water charges for a fixed volume of water that customers pay in return for provision of water; (Q) is the quantity of water sold to all the customers of a water utility; (In) is a vector of institutional and cost of providing service characteristics of water utilities; (En) is the index of water quality; and (Ge) is geographical characteristics of the sample.

Following Kim (1987), Kim Kim (1988), Fabbri and Fraquelli (2000), Fumitoshi and Urakami (2007), Filippini (1983), and Ansink and Houba (2012), we control for both economies of size and scale to account for quantity of water sold. Each of these studies distinguish between output scale and network scale effects (economies of size and scale). In the institutional category, we utilize variables of primary water source (i.e. ground water, surface water, or purchased water), network line length, long term debt, and volume of water loss in water production cycles. Bae (2007) controlled for different water right doctrines (i.e. riparian rights versus prior appropriation), different ownerships for water supply (i.e., public water versus private water systems), and different pricing mechanisms (i.e. uniform rates, increasing block rate, or decreasing block rates). Our observations are within a single state where more than 80 percent of all municipal water utilities follow a declining block rate structure. Since there is no significant heterogeneity in block rates, our final estimation does not control for this variable.

Although regulated by the West Virginia Bureau of Public Health (WVBPH), the quality of water provided by each municipal utility differs depending upon the number of violations to drinking water standards. We introduce two variables to reflect violations during 2014: 1) the number of violations reported for each water utility, and 2) a dummy variable as an indicator of having a water violation or not. Out of 125 observations, 72 municipalities did not have any reported violations in 2014. Finally, in geography category, we include variables reflecting elevation changes and differences in slope within a municipality's boundary along with population density. Table 1 shows the explanatory variables in each category.

Table 1: Categorization of explanatory variables

Variable	Category
Sold water (million gallons)	Quantity
Sold water per customer (million gallons)	Quantity
Network length (miles/customer)	Institutional
Debt ($1,000/customer)	Institutional
Water loss (%)	Institutional
Groundwater as source	Institutional
Violations (number in 2014)	Institutional
Elevation difference (ft)	Geographical
Average slope (%)	Geographical
Population density (person/sq. mile)	Geographical

Based on equation (1), an empirical equation for water charges can be written as:

$$
\begin{aligned}
WC_i = &\beta_0 + \beta_1 Line_i + \beta_2 Sold_i + \beta_3 Sold_i^2 + \beta_4 SoldPC_i + \beta_5 SoldPC_i^2 \\
&+ \beta_6 Debt_i + \beta_7 Loss_i + \beta_8 Ground_i + \beta_9 PopulationD_i \\
&+ \beta_{10} PopulationD_i^2 + \beta_{11} Violation_i + \beta_{12} ElevationDif_i + \epsilon_i
\end{aligned}
\tag{2}
$$

However, as pointed out by Hervé and Vermersch (1989) and Filippini (1983), estimation of a translog variable cost function with a high number of explanatory variables can lead to multicollinearity problems. Thus, we examine three functional forms for the water charges model: a linear with quadratic variables, a Cobb-Douglas (log of dependent and independent variables), and a spatial model.

Our approach here is to first estimate a model for water charge and then by controlling for spatial spillovers, we estimate another model in a spatial framework. According to James and Pace (2009) and Elhorst (2014), under non-spatial econometric estimation, observed values do not depend on location. They are independent points and therefore there is no correlation between them and their neighbors. However, LeSage and Pace James and Pace (2009) explain that in the case of spatial dependency: “In contrast to point observations, for a region we rely on the coordinates of an interior point representing the center (the centroid). An important point is that in spatial regression models each observation corresponds to a location or region”. In non-spatial models, each observation has a mean of $x_i\beta$ and a random component ϵ_i where the observation i represents a region or point in space at one location and is considered to be independent of observations in other locations. In other words, independent or statistically independent observations imply that $E(\epsilon_(i)\epsilon_j) = E(\epsilon_i)E(\epsilon_j) = 0$. This assumption of independence greatly simplifies models.

In most cases this assumption is not applicable and observations in different points or regions are dependent LeSage and Pace 2009. Suppose we have two neighbors (regions) i and j. If these two regions are spatially correlated and normality for error terms is assumed, then:

$$y_i = \rho_i y_j + x_i\beta + \epsilon_i \tag{3}$$

$$y_j = \rho_j y_i + x_j\beta + \epsilon_j \tag{4}$$

where the dependent variable in neighbor j influences the dependent variable in neighbor i and vice versa. After examining spatial dependency of our dependent variable with a Moran’s I test[1] (Moran’s i index = 0.113, P-value

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[1] For more information, please see Li et al. (2007).

= 0.030), this result show spatial dependency and the need to apply spatial econometrics modeling.

There are five different spatial models. The first is the spatial autoregressive lag model (SAR) as shown in equations 3 and 4. Spatial Error Model (SEM) assumes dependency in error term. A SLX model or spatial lag of explanatory variable assumes that only explanatory variables play a direct role in determining dependent variables. Lastly, the Spatial Durbin Model (SDM) and Spatial Error Durbin Model (SDEM) include spatial lags of the explanatory variables as well as the dependent variable and a spatial lag of the explanatory variables (WX) along with spatially dependent disturbances.

All spatial models have a weight matrix (W), which quantifies the connections between regions. Elhorst (2014) names the weight matrix as a tool to describe the spatial arrangement of the geographical units in the sample. There are variety of units of measurement for spatial dependency such as neighbors, distance, and links (Getis (2007)). The spatial weight matrix is based on the distance between municipalities. In this study, we applied seven nearest-neighbors weight matrix[2] . Spatial econometric models are estimated using software codes provided by Donald Lacombe[3] .

For the minimum monthly access charge model, we include variables reflecting cost, social equity, municipal governance, city size, and fixed cost considerations. Brown (2007) explains that minimum charges are established to provide an essentially guaranteed base revenue stream for the utility. V. and Tsitsifli (2010) argue that the determination of the fixed charge has to be based on the actual water charge. Besides water charge, we introduce social demographics of a municipality such as percentage of elderly population, median household income, and percentage of population below the poverty level to the minimum charge equation to see whether these socioeconomic characteristics influence the minimum monthly charge for access to water provision.

The general form for a minimum access charge equation for water provision is:

$$MMC_i = f(WC_i, SE_i, SM_i, CS_i, WL_i) \tag{5}$$

where (MMC) stands for the minimum monthly charge set by the municipal water utility i, (WC) is the water charge, and (SE) shows the socioeconomic factors as indicators of social equity concerns influencing minimum charges.

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[2] Lesage and Pace (2010) argue that the configuration of the spatial weight matrix matters very little

[3] Available at: http://myweb.ttu.edu/dolacomb/matlab.html

SM is a dummy variable to describe municipality governance. This variable is included in the minimum monthly access charge model to examine whether local politics influenced this charge. A “strong” mayor-council type of government is compared to a “weak” mayor-council and council-manager. Under a “strong” mayor-council government, a mayor is elected separately and has substantial administrative and budgetary authority above the council (National League of Cities 2013). It is hypothesized that a “strong” mayor type of government would result in more political pressure to keep minimum charges low relative to a “weak” mayor or council-manager. There is some evidence in the literature that the existence of a “strong” mayor inhibits the implementation of policies such as market-based ideas within municipalities (Krebs and Pelissero (2010), Bae (2013)).

The CS variable measures the effect of city size on minimum monthly water charge. As we explained earlier, minimum charge represents a fixed proportion of the water charge that each residential household customer must pay regardless of their water consumption. Since West Virginia is a small, mostly rural state, there are few large cities (only one over 50,000 in population). Thus, the size variable utilized was a distinction between class II municipalities (10,000 to 50,000 in population) versus class III and IV municipalities (less than 10,000). The logic for this variable is that larger municipalities imply a greater tax base from which there may be an increased ability of the municipality to absorb losses that might be incurred from lower minimum monthly access charges. Lastly, we include a variable to measure water loss (WL). The WL variable examines whether fixed costs like water losses influence the minimum water charge.

The empirical model for minimum monthly access charges is:

$$MC_i = \beta_0 + \beta_1 WC_i + \beta_2 PCI_i + \beta_3 SR_i + \beta_4 HO_i + \beta_5 SM_i + \beta_6 CS_i + \beta_7 L_i + \epsilon_i \tag{6}$$

where (PCI) is average per capita income; (SR) is the percentage of households with one or more above 65-year-old; and (HO) is the percentage of households own a house unit. To avoid a simultaneity issue, predicted water charges from equation 2 are utilized for MC since both water charges and minimum charges are proposed simultaneously by water utilities to the WV PSC. We conducted robustness checks with the socioeconomic and demographic characteristics by examining different combinations of these variables in models.

4 Data

Data for this research are primarily based on the annual reports submitted to the WVPSC by municipal water utilities in West Virginia. These annual reports for water utilities are available through WVPSC website[4] and data were collected for 2014. These reports contained numerous missing values – mostly for total treatment capacity, total main line, total long term debt, and water source. According to the WVPSC, there is no obligation for utilities to provide the information in their annual report. Thus, additional information was gathered through email and phone calls to utility personnel about missing data or when information in a report seems questionable.

Additionally, water quality violation data are based on the 2014 annual report of environmental engineering division of the WVBPH. The report includes violations for: maximum contaminant level, monitoring/reporting, or treatment technique which were submitted throughout the year. The Natural Resource Analysis Center at West Virginia University provided the necessary topography data within municipality boundaries, maximum elevation, minimum elevation, elevation difference, and the average slope. Municipal population size is derived from the 2014 population estimates of the U.S. Census Bureau 2015.

A total of 14 cities in West Virginia have a population greater than 10,000, nine of these municipalities are in our data base. For local governance, historically, most municipalities in West Virginia have implemented a mayor-council type of government (Richard et al. (1996)). This type of government was selected as the base and compared to a strong mayor type. Municipalities with a strong mayor were determined from an on-line search of municipal government web pages and a description of their governing structure. Of the 125 municipalities in the database, only nine have a strong mayor type.

For the log-log models, a value of 0.1 is used to replace zeros in all variable observations of zero with the exception of the violations variable. This allowed for conversion of variables to log values at a small value close to zero. Since the violations variable is expressed as integers only, we added +1 to the current values.

Tables 2 and 3 show the data summary statistics and expected coefficient signs for the independent variables in the water charge and the minimum monthly access charge models. Due to considerations of economies of size and scale, negative coefficients are expected for population density,

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[4] Available at: http://www.psc.state.wv.us/Annual_Reports/default.htm

Table 2: Summary statistics of variables used in the water charge model

Variable	Mean	Standard Deviation	Min	Max	Expected sign of coefficient
Water charges ($)	38.71	11.88	13.26	71.89	
Network length (miles/customer)	0.04	0.27	0.001	3.10	+
Sold water (million gallons)	137.34	295.26	13	11,374	-
Sold water per customer (million gallons)	0.06	0.08	0.002	0.83	-
Debt ($1,000/customer)	1.52	1.42	0	6.03	+
Water loss (%)	24.59	17.23	0	92.32	+
Groundwater as source	0.26	N/A	0	1.00	-
Population density (person/sq. mile)	1,316.60	786.37	125.94	5,778.89	-
Violations (number in 2014)	2.46	5.15	0	34	-
Elevation difference (ft)	452.92	234.11	71.99	1285.03	+
Average slope (%)	18.834	11.175	4.62	55.82	+

water sold, and the water sold per customer. We expect a positive coefficient for main line length due to added infrastructure costs. Since ground water typically requires less treatment than surface water, we expect a negative coefficient for the ground water source variable. Also, the violation coefficient is expected to be negative as the number of violations stem from lower quality source water and less treatment. To control for the degree of elevation changes within the utility service area, we introduce two topographic variables: difference between maximum and minimum elevation and average percent slope (Feinerman et al. (2016)). We expect both to have negative coefficients - more changes in topography, the higher the cost of providing water due to higher costs of water transmission in hilly areas.

For the minimum monthly access charge equation, we expect a positive sign for water charge. If social equity matters in setting minimum water charges, then income, education, and home ownership variables are expected to have positive coefficients. Also with social equity concerns, the percent of residents who are below the poverty line and the percentage of elderly households both should have negative impacts on minimum charges.

Table 3: Summary statistics of variables used in the minimum monthly access charge

Variable	Mean	Standard Deviation	Min	Max	Expected sign of coefficient
Minimum monthly charge ($)	20.99	7.11	3.87	39	
% HHs with 1 and >1 older than 65	31.32	7.99	10.34	49.53	-
Percentage of population (%) older than 65	17.62	5.82	4.60	37.50	-
Median Income ($)	34,892.09	12,263.78	12,344	106,250	+
Per capita Income ($)	19,719.85	6,473.85	4,472	64,099	+
Percentage below (%) poverty rate	22.61	9.96	0.1	55.3	-
Percentage of home (%) ownership	67.44	12.96	29.90	92.70	+
Percentage of bachelor (%) degree or higher	14.64	10.32	0.1	65.80	+
Class II municipalities	0.06	N/A	0	1	-
Strong Mayor	0.04	NA	0	1	-
Water loss (%)	24.59	17.23	0	92.32	+

5 Results

We estimate regressions using water charge per 4,500 gallons and the minimum monthly access charge as dependent variables. Institutional, governmental, geographical, environmental, and socioeconomic factors are independent variables. For the water charges model, ten different specifications are estimated. The first six one are linear functional form (Table 4) and the remaining four are in log-log form (Table 5). Variables that are highly correlated with the number of customers are altered to per capita to avoid multicollinearity (network length, sold water, debt).

In the water charges model with a linear function form, coefficient p-values consistently below 0.05 are: sold water per capita; total debt; groundwater as a water source, and population density (Table 4). The network length variable has a coefficient with p-values under 0.10, while water loss, elevation difference and violation variable coefficients consistently have p-values much above 0.05 (Table 4). Our expectations for positive coefficient signs on geographical variables (elevation difference and slope) and negative coefficient signs for violation variables are not met by the linear functional form models, however, their p-values are all above 0.10.

To interpret the results from Model 1, a one person increase per square mile will decrease the water charge by \$0.01. Although based on the quadratic form of population density, this is true up to a certain point (5000 people/square mile), after this point, population density will actually start to increase water charges. Other interpretations of 4,500 gallon charges include: increasing the total long-term debt by one thousand dollars per customer will increase this charge by \$1.84, use of groundwater as a primary water source reduces this charge by \$5.11, and an increase of one mile in main line length per customer will increase this charge by \$5.20.

The log-log (Cobb-Douglas) functional form coefficients reported in Table 5 correspond to elasticities. The coefficient sign results match the linear functional form results for all variables. Variable coefficients with p-values below 0.05 include: sold water, debt, and groundwater. Model 7 has the highest F-statistic value and we continue our interpretation based upon this model. Among all the determinants, groundwater as a water source has the largest impact on water charge. When groundwater is source of water for a municipal utility, the water charge to household customers is 17% lower compared to utilities with surface or purchased water as their primary water source. For 1% changes in the quantity of sold water and long-term debt, water charges are reduced 6% and increased 2%, respectively.

To choose the most representative weight matrix for the data, we test different sets of nearest neighbor relationships. The seven nearest neighbors' weight matrix has the highest log likelihood value among the eight matrices examined. Since log-likelihood has the power to compare the models, this test guides us to our particular specification (Kalenkoski and Lacombe, 2013). Table 6 shows the result of choosing the most appropriate weight matrix.

To examine spatial correlation among observations, we utilize five different spatial models (i.e. SAR, SEM, SDM, SDEM, and SLX). Table 7 shows the results for the SAR model since this model is the only one with a significant spatial component. We report the other specifications in Appendix I. Model 1 specification is used in a spatial framework because among all the linear and log-log functional forms, this model has the highest adjusted R^2. In the SAR model, there is a positive and statistically significant spillover effect. This result means that water charges in neighboring municipal utilities have positive spillover effects on the water charge of a particular municipal utility. In other words, since water charges are spatially dependent, if charges increase in a neighboring municipal j, then water charges in municipal i will increase as well. Compared to Model 1 results in Table 4, the magnitude of the direct effects in Table 7 are similar to the coefficients for each variable. While none of the indirect effects have p-values even close to 0.10, the total effect impacts in the SAR model have an increased magnitude of impact on water charges. For example, groundwater as a water source has an estimated total impact of reducing water charges by \$6.45 in the SAR model compared to the linear model estimate of \$5.11.

Finally, for the minimum monthly charge model, we specify a linear functional form in estimating coefficients. Since education, percent below poverty, and income variables are highly correlated, we run four different regression models to control for these factors in separate models (Table 8). Examining Model A, predicted water charge has a positive coefficient with a very small p-value. On average, minimum monthly access charges incorporate about 40% of the municipal utility's 4,500 gallon charge. Socioeconomic factors included in this model are households with one or more residents over 65, per capita income, and home ownership rate. All of these variable coefficients have p-values well above 0.10. Strong mayor has a coefficient p-value slightly below 0.10 with a negative impact on minimum charge, about \$4.50 per month. The water loss coefficient has a p-value at 0.10 and shows a slight rise in minimum charge (\$0.01) for each additional 1% water loss. The variable for municipal size (class II municipalities) does not impact minimum charges. None of the four models have coefficients for elderly or poverty variables with p-values below 0.05 (Table 8). Overall, the results of these

Table 4: Results of the water charges model in linear functional form

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Network length	5.20	5.25	5.64	5.69	5.98	4.32
	(0.096)	(0.094)	(0.071)	(0.070)	(0.065)	(0.176)
Sold water (000)	-8.82	-8.52	-11.30	-10.95	-12.72	-10.42
	(0.282)	(0.301)	(0.175)	(0. 190)	(0.131)	(0.216)
Sold water^2 (000)	0.0007	0.0006	0.0014	0.0013	0.0023	0.0012
	(0.859)	(0.879)	(0.721)	(0.743)	(0.577)	(0.756)
Sold water pc	-126.40	-130.11	-124.44	-128.17	-125.77	-4.17
	(0.006)	(0.004)	(0.007)	(0.006)	(0.008)	(0.704)
Sold water pc^2	147.79	152.02	145.24	149.51	148.44	-
	(0.006)	(0.005)	(0.007)	(0.006)	(0.008)	
Debt	1.84	1.82	1.83	1.81	2.04	1.72
	(0.002)	(0.003)	(0.002)	(0.003)	(0.001)	(0.005)
Water loss	0.05	0.05	0.05	0.05	0.04	0.07
	(0.281)	(0.25)	(0.305)	(0.282)	(0.371)	(0.140)
Groundwater (%)	-5.11	-4.98	-5.61	-5.48	-5.56	-5.13
	(0.008)	(0.011)	(0.003)	(0.005)	(0.005)	(0.010)
Population density (000)	-10.01	-10.20	-9.87	-10.06	-2.25	-10.22
	(0.000)	(0.000)	(0.000)	(0.000)	(0.063)	(0.000)
Population density^2 (000)	0.002	0.002	0.002	0.002	-	0.002
	(0.002)	(0.001)	(0.002)	(0.002)		(0.002)
Violations	0.17	-	0.16	-	0.24	0.20
	(0.323)		(0.332)		(0.172)	(0.253)
Violations dummy	-	1.07	-	1.07	-	-
	(0.567)		(0.573)			
Elevation difference	-0.006	-0.006	-	-	-0.005	-0.007
	(0.110)	(0.121)			(0.201)	(0.082)
Average slope	-	-	-0.10	-0.10	-	-
	(0.206)	(0.226)				
Constant	55.54	55.88	54.86	55.19	48.92	49.54
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Adj. R^2	0.32	0.32	0.32	0.28	0.27	0.27
F-statistic	5.91	5.82	5.78	5.95	5.17	5.43
Number of observations	125	125	125	125	125	125

Note: P-values in parenthesis
pc: per customer

Table 5: Results of the water charges model in log-log (Cobb-Douglas) functional form

Variable	Model 7	Model 8	Model 9	Model 10
Network length	0.015	0.15	0.20	0.21
	(0.623)	(0.624)	(0.511)	(0.514)
Sold water (000)	-0.06	-0.06	-0.06	-0.06
	(0.022)	(0.023)	(0.010)	(0.011)
Sold water pc	-0.06	-0.06	-0.05	-0.05
	(0.300)	(0.278)	(0.337)	(0.311)
Debt	0.02	0.02	0.02	0.02
	(0.008)	(0.009)	(0.009)	(0.010)
Water loss	0.003	0.003	0.004	0.005
	(0.875)	(0.875)	(0.807)	(0.802)
Groundwater	-0.17	-0.17	-0.18	-0.18
	(0.002)	(0.002)	(0.001)	(0.001)
Population density	-0.08	-0.08	-0.07	-0.07
	(0.094)	(0.080)	(0.129)	(0.113)
Violations	0.03	-	0.03	-
	(0.208)		(0.203)	
Violations dummy	-	0.05	-	0.05
		(0.339)		(0.341)
Elevation difference	-0.05	-0.05	-	-
	(0.256)	(0.261)		
Average slope	-	-	-0.03	-0.03
			(0.457)	(0.488)
Constant	4.72	4.7	4.4	4.6
	(0.000)	(0.000)	(0.000)	(0.000)
Adj. R^2	0.26	0.26	0.26	0.25
F-statistic	5.92	5.81	5.80	5.69
Number of observations	125	125	125	125

Note: P-values in parenthesis
pc: per customer

Table 6: Log-likelihood values for nearest neighbor weight matrices

Nearest neighbor weight matrix	Rho Value	Log-likelihood value
knn = 1	0.034	-404.9399
knn = 2	0.055	-404.9098
knn = 3	0.123	-404.3130
knn = 4	0.179	-403.7208
knn = 5	0.147	-404.3005
knn = 6	0.199	-403.8745
knn = 7	0.234	-403.6541
knn = 8	0.202	-404.2045

models show that socioeconomic factors within municipal populations do not contribute to equity considerations explaining variations in municipal utility minimum charges.

The minimum monthly access charge model also is examined for spatial impacts. We repeat the same procedure as the water charge model in order to choose the most appropriate weight matrix (Table 9). The seventh nearest neighbor weight matrix has the highest log-likelihood, so that we continue the rest of spatial econometric estimations based upon influences from the seventh nearest neighbors. The results of the SAR and SEM estimations (the only two spatial models with a significant spatial component) for Model A are presented in Table 10. The results for the other three spatial models are presented in Appendix II.

Among the explanatory variables, again only water charge has a coefficient with a p-value below 0.05 (Table 10). Water charges have positive effects on the minimum monthly access charges (both direct and indirect in the SAR model). This result means that predicted water charges in municipal i influence not only the minimum water charge in municipal i, but also influence the minimum water charge in neighboring j municipalities. This spillover effect from water charges is about 1/3 the size of the direct effect. Also, the SEM model result shows that there are some significant spillover effects of variables that are not explicitly modeled (error term). Except for the negative total effect by strong mayor, none of the other variable coefficients in Table 10 show evidence of statistical significance.

Table 7: Results of the SAR model estimation for Model 1

Variable	Direct effect	Indirect effect	Total effect
Network length pc	5.15	1.87	7.03
	(0.087)	(0.442)	(0.131)
Sold water (000)	-8.33	-2.15	-10.48
	(0.285)	(0.544)	(0.315)
Sold water^2	0.0004	0.00007	0.0005
	(0.915)	(0.992)	(0.936)
Sold water pc	-125.33	-44.37	-169.71
	(0.004)	(0.368)	(0.026)
Sold water pc^2	146.86	51.88	198.75
	(0.004)	(0.366)	(0.025)
Debt pc	1.84	0.65	2.50
	(0.001)	(0.347)	(0.015)
Water loss	0.05	0.02	(0.07)
	(0.234)	(0.511)	(0.273)
Groundwater	-4.83	-1.61	-6.45
	(0.008)	(0.339)	(0.020)
Population density (000)	-9.87	-2.59	-12.46
	(0.000)	(0.336)	(0.009)
Population density^2 (000)	0.002	0.0004	0.0022
	(0.001)	(0.346)	(0.015)
Violation	0.15	0.04	0.20
	(0.346)	(0.590)	(0.378)
Elevation difference	-0.005	-0.001	-0.007
	(0.126)	(0.432)	(0.157)
Constant	-	-	45.45
			(0.000)

Table 8: Results of the minimum monthly access charge model

Variable	Model A	Model B	Model C	Model D
Predicted Water Charge per 4,500 gal	0.39	0.39	0.4	0.4
	(0.000)	(0.000)	(0.000)	(0.000)
Household with one or more older than 65	0.04	-0.04	-	-0.04
	(0.638)	(0.647)		(0.639)
Percentage of population older than 65	-	-	0.01	-
			(0.926)	
Per capita income (000)	-0.04	-	-0.04	-
	(0.658)		(0.662)	
Median HH income (000)	-	0.21	-	-
		(0.625)		
Bachelor degree or more	-	-	-	-0.007
				(0.911)
Home ownership rate	0.06	0.04	0.07	0.06
	(0.264)	(0.433)	(0.169)	(0.234)
Percent below poverty	-	-	-	0.03
				(0.603)
Class II municipalities	-1.20	-1.38	-1.25	-1.12
	(0.645)	(0.587)	(0.606)	(0.662)
Strong Mayor	-4.55	-4.49	-4.48	-4.60
	(0.095)	(0.099)	(0.101)	(0.099)
Water loss	0.01	0.01	0.01	0.01
	(0.100)	(0.105)	(0.733)	(0.749)
Constant	1.02	0.45	1.45	-1.07
	(0.823)	(0.927)	(0.764)	(0.860)
Adj. R^2	0.19	0.19	0.19	0.19
Number of observations	125	125	125	125

Note: P-values in parenthesis

Table 9: Log-likelihood values for nearest neighbor weight matrices

Nearest neighbor weight matrix	Rho Value	Log-likelihood value
knn = 1	0.150	-357.555
knn = 2	0.182	-358.487
knn = 3	0.228	-358.004
knn = 4	0.273	-357.449
knn = 5	0.267	-358.586
knn = 6	0.316	-357.826
knn = 7	0.330	-357.375
knn = 8	0.246	-359.640

Table 10: Results of the minimum monthly access charge model

Variable	Direct effect	Indirect effect	Total effect	
Predicted Water Charge	0.33	0.11	0.44	0.39
per 4,500 gal	(0.000)	(0.000)	(0.000)	(0.000)
Household with one or	0.03	0.01	0.04	0.04
more older than 65	(0.524)	(0.589)	(0.534)	(0.649)
Per capita income (000)	-0.04	-0.02	-0.06	-0.028
	(0.710)	(0.759)	(0.720)	(0.746)
Home ownership rate	0.04	0.01	0.05	0.06
	(0.238)	(0.368)	(0.259)	(0.230)
Class II municipalities	-1.68	-0.68	-2.37	-0.38
	(0.647)	(0.708)	(0.659)	(0.824)
Strong Mayor	-4.62	-1.70	-6.33	-4.04
	(0.118)	(0.276)	(0.099)	(0.115)
Water loss	0.006	0.001	0.007	0.001
	(0.855)	(0.898)	(0.864)	(0.959)
Constant	-	-	-5.25	1.51
			(0.31)	(0.736)

Note: P-values in parenthesis

6 Conclusions

Previous studies on water cost estimation have neglected both geography and spillover aspects regarding factors explaining the cost of providing water, although some researchers explicitly recommend controlling for these variables (Barbara and Filippini (2001)). As discussed earlier, the main goal of this study is first to estimate the influences of primary factors on water charges and secondly, to estimate the determinants of minimum monthly access charges across municipalities in West Virginia. Our estimation of the water charge model show that the quantity of water sold per customer, population density, ground water as a primary source of water, and utility debt source are the most important explanatory factors for residential water charges. In addition, main line length is sometimes an influential factor to explaining water charges.

The addition of geographic variables of elevation difference and slope did not have their expected impact on water charges. There are a couple of explanations for this result. First, the locations water utility plants are unknown and if it is located in an area with minimum elevation, the cost of transmission would be larger than when it is located in a maximum elevation area. Secondly, water utility boundary of service may be different than the municipal boundary, which could influence the result. Utility boundary data are not accessible to the public.

From our model results, groundwater as a water source lowers water charges by about \$5 to \$6 per 4,500 gallons (approximately a 15% reduction in customer cost). This result demonstrates the importance of protecting groundwater quality with source water protection programs. According to Environmental Protection Agency, states, local governments, and utilities all play important roles in water protection programs. Providing a wellhead protection program for ground water and watershed management programs for surface water are among services that states offer to water utilities.

In West Virginia, implementation of the wellhead protection program began in the early 1990's as a part of ground water protection strategy to encourage utilities to develop protection and management plans. The WVBPH assesses all of West Virginia's public water systems and creates polices to provide clean and safe drinking water. Our water charge model results provide the basis for a rough estimate of the benefits from ground water protection. Allowing for a \$5 saving for each 4,500 gallons of use, the over 240,000 households in West Virginia served by municipalities using groundwater have an annual cost savings of \$3.6 million in their water charges compared to other water sources.

Similar to Bae 2007, we find that utility debt also impacts water charges. For every \$1,000 of utility debt, water charges increase by about \$2 per 4,500 gallons. Given the mean of debt per customer and 4,500 gal of water use monthly, utility debt adds about \$36 to the annual household water bill (about an 8% increase). This result demonstrates the importance of grant versus loan financing to utilities. As reported by the Environmental Finance System , different organizations provide long term fixed low-interest loans to rural areas and low-income communities to help them to increase the water quality. Prior to the 1987 amendments to the Clean Water Act, municipal utility assistance was provided through grants with the federal government picking up 55% of project cost. This amendment changed grants to low-interest rate loans. This change means that now local governments are responsible for 100% of projects' cost (Copeland (1999)). This societal change of replacing the federal government grants to municipal utilities with low-interest loans has increased long term utility debt, which has increased water charges to customers.

The population density variable has a negative effect on water charges in all model specifications, which means more dense areas have lower water charges. Given the quadratic specification, this negative impact occurs only up to a certain point (5,000 people/square mile). This is also true for the total water sold to customers. In other words, although municipalities in West Virginia are small, size and scale impacts are still found in small municipalities.

In addition, there are modest, but statistically significant (evaluated at a p=0.05 or lower) levels of spatial autocorrelation in both models among West Virginia municipal water utilities in terms of water charges and minimum monthly access charges. This result shows that both these pricing decisions are influenced by neighboring utilities. While none of the variables in the water charges model had statistically influential, indirect impacts, water charges in the minimum monthly access charge model had a positive indirect impact with a p-value below 0.10. Thus, an increase in water charges in municipal utility i leads not only to a higher minimum charge in municipality i, but also higher minimum charges in neighboring j municipalities due to positive spillover effects.

When examining minimum charges, there is some evidence that utilities located in strong mayor governing system assess lower minimum charges than other municipalities. Overall, minimum charges are closely related to water charges – incorporating about 40% of the water charge for 4,500 gallons into the minimum charge. To examine the share of household income taken up by water charges in West Virginia municipalities, we calculated the average water use for each household multiplied the water charge and divided by the average household income. On average, West Virginia households pay far below the OECD standard of 3% to 5% of household income for water. Our results indicate that the average share of water costs across West Virginia households with municipal water utilities is 1.5% of household income devoted to water charges with a maximum share being 4%. With such reasonable costs of water for households, this could be a factor explaining why our models find no significant effects from socioeconomic factors on monthly minimum charges for access to water.

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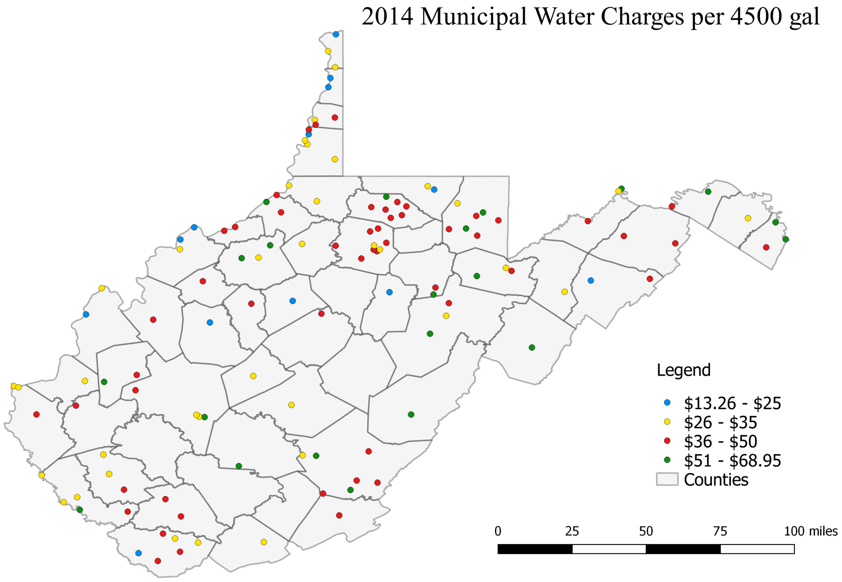
Appendix 1 - Estimation results for SEM, SDM, SLX, and SDEM models

Variable	SEM	SDM	SLX	SDEM
Network length pc	5.34	4.64	4.64	4.7
	(0.064)	(0.000)	(0.161)	(0.10)
Sold water (000)	-6.86	-6.96	-6.92	-6.78
	(0.219)	(0.325)	(0.451)	(0.395)
Sold water square (000)	0.0006	-0.0006	-0.0006	-0.0007
	(0.843)	(0.863)	(0.889)	(0.852)
Sold water pc	-123.33	-157.10	-156.98	-157.57
	(0.000)	(0.000)	(0.001)	(0.000)
Sold water pc square	145.40	187.19	178.11	178.11
	(0.000)	(0.000)	(0.002)	(0.000)
Debt pc	1.81	2.01	2.01	2.00
	(0.001)	(0.000)	(0.002)	(0.000)
Water loss	0.08	-0.03	0.04	0.03
	(0.222)	(0.398)	(0.478)	(0.424)
Ground water	-5.13	-5.004	-5.005	-4.96
	(0.005)	(0.004)	(0.022)	(0.009)
Population density (000)	-9.15	-9.15	-9.16	-9.18
	(0.000)	(0.000)	(0.001)	(0.000)
Population density square (000)	0.002	0.002	0.016	0.016
	(0.001)	(0.002)	(0.009)	(0.002)
Violation	0.14	0.09	0.09	0.095
	(0.357)	(0.554)	(0.607)	(0.563)
Elevation difference	-0.005	-0.004	-0.004	-0.004
	(0.136)	(0.311)	(0.381)	(0.328)
Constant	54.70	70.94	70.54	71.00
	(0.000)	(0.000)	(0.000)	(0.000)
rho	-	0.005	-	-
		(0.962)		
Lambda	0.18	-	-	-0.05
	(0.221)			(0.767)
W* Network length pc	-	-4.82	-4.85	-4.47
		(0.000)	(0.567)	(0.529)
W* Sold water (000)	-	4.08	4.6	4.92
		(0.856)	(0.882)	(0.823)
W* Sold water square (000)	-	-0.01	-0.01	-0.01
		(0.349)	(0.445)	(0.320)
W* Sold water pc	-	-197.44	-196.18	-203.04
		(0.000)	(0.253)	(0.000)
W* Sold water pc square	-	186.88	185.58	191.23
		(0.000)	(0.326)	(0.000)
W* Debt pc	-	1.97	1.95	2.03
		(0.200)	(0.296)	(0.190)

continued- Appendix 1 - Estimation results for SEM, SDM, SLX, and SDEM models

Variable	SEM	SDM	SLX	SDEM
W* Water loss	-	-0.07	-0.07	-0.06
		(0.536)	(0.643)	(0.620)
W* Ground water	-	0.68	0.72	-0.36
		(0.014)	(0.88)	(0.927)
W* Population density (000)	-	-5.57	-5.44	-5.78
		(0.274)	(0.506)	(0.421)
W* Population density square (000)	-	0.001	0.01	0.001
		(0.453)	(0.553)	(0.472)
W* Violation	-	0.58	0.58	0.57
		(0.332)	(0.426)	(0.342)
W* Elevation difference	-	-0.003	-0.003	-0.003
		(0.645)	(0.765)	(0.716)
R- square	0.37	0.44	0.44	0.44
Number of observations	125	125	125	125

Figure 1: Map of West Virginia municipal utilities and their 2014 water charges.



Appendix 2 - Estimation results for minimum water charge SDM, SLX, and SDEM models

Variable	SDM	SLX	SDEM
Predicted Water Charge per 4,500 gal	0.36	0.37	0.36
	(0.000)	(0.000)	(0.000)
Household with one or more older than 65	0.04	0.04	0.05
	(0.619)	(0.682)	(0.563)
Per capita income (000)	-0.008	0.008	0.027
	(0.932)	(0.921)	(0.759)
Home ownership rate	0.06	0.06	0.05
	(0.955)	(0.340)	(0.377)
Class II municipalities	-1.02	-1.06	-1.20
	(0.135)	(0.658)	(0.609)
Strong Mayor	-4.56	-5.01	-4.75
	(0.368)	(0.073)	(0.072)
Water loss	0.007	-0.006	-0.007
	(0.825)	(0.855)	(0.823)
Constant	8.51	9.38	8.60
	(0.620)	(0.609)	(0.643)
Rho	0.24	-	-
	(0.097)		
Lambda	-	-	0.12
			(0.198)
W* Predicted water charge	-0.04	0.06	0.07
	(0.718)	(0.952)	(0.897)
W* Household with one or more older than 65	-0.04	-0.23	-0.01
	(0.760)	(0.860)	(0.860)
W* Per capita income	-0.03	-0.04	-0.04
	(0.750)	(0.725)	(0.720)
W* Home ownership rate	-0.01	-0.01	-0.01
	(0.627)	(0.603)	(0.615)
W* Class II	-10.29	-11.40	-11.16
	(0.112)	(0.095)	(0.112)
W* SM	-2.27	-4.77	-6.52
	(0.639)	(0.454)	(0.374)
W*water loss	0.064	0.07	0.06
	(0.408)	(0.365)	(0.435)
R- square	0.28	0.28	0.29
Number of observations	125	125	125