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

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Examining both spatial and non-spatial econometric analyses with a dataset of 125 municipal water utilities, we investigate utility cost and community factors that explain variation in residential user charges and monthly access charges for water. The results of water charges model are consistent with the theory of water cost determination as water source, debt, and economies of size plus scale influence residential consumer charges for water. Both models (water charges and minimum monthly access) displayed positive spillover effects, although the only variable in either model with a significant indirect effect is water charges on minimum monthly access charges. Based upon model results, ground water use by utilities lowers water charges and is estimated to save residential 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 monthly charges for access.

Keywords: Residential water charges; social equity; municipal utilities; spatial econometrics.

1. Introduction

Water is a basic resource that is vital for the existence of life. Because of this, provision of potable water is often discussed as a basic human right (United Nations 2010). While a renewable resource, the global water cycle implies essentially a fixed water supply (Renzetti 2012). Increasing demands for water strain

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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 US cities with a range for the same volume of water from \$23.26 (in Fresno, CA) to \$153.78 (in Santa Fe, NM). These price data were calculated as a monthly bill for a family of four using 100 gallons per person per day.

Provision of clean and reliable water is a key element of any developed society. Water markets are mostly dominated by monopolists or at least ones that contain monopoly elements (Klein 1996). The lack of any feasible and realistic competition makes it necessary to have a regulatory mechanism in place to deal with the loss of social welfare imposed by a monopoly market. In West Virginia, the provision of water services occurs as a regulated monopoly. The West Virginia Public Service Commission (WV PSC) provides oversight for this necessary government function to ensure that consumers have access to safe and reliable water supplies at reasonable rates. Through the WV PSC, municipal utilities operate as monopolies within their communities because of the capital intensive structure of operating a water utility.

Pricing regulation by the WV PSC is based on the costs faced by water providers. However, when water charges across West Virginia municipalities are examined on the basis of cost to residential customer for 4,500 gallons, a more than five-fold difference is observed (from \$13.26 in Vienna to \$71.89 in Matoaka) (WV PSC 2014). This range is comparable to that found at a national level even with a much more homogenous regulatory and institutional climate exiting in West Virginia. Figure 1 demonstrates the spatial distribution 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; Rijsberman 2006; Ercin and Hoekstra 2014; World Economic Forum 2015; Mekonnen and Hoekstra 2016), our main research objective is to examine what factors impact the water charges that household consumers pay across municipal water utilities in West Virginia. Factors are selected for a water charges model based on those that potentially influence municipal utility costs of providing water. Thus, we employ a municipal utility cost-based approach to determine what factors explain water charge 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

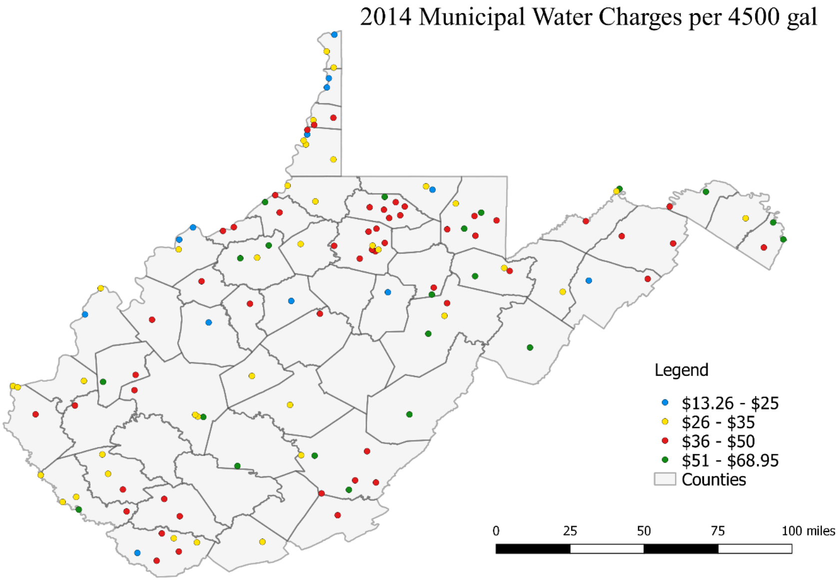

Figure 1. Map of West Virginia Municipal Utilities and their 2014 Water Charges

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). This structure, as first stated by Coase (1946), notes that an efficient price in a regulated market needs to be expressed as a two-part tariff with a volumetric price equal to marginal cost and a fixed fee equal to each customer's share of fixed costs.

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 municipal water utilities. We will investigate whether minimum charges by utilities vary based upon socioeconomic circumstances within a community. 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.

Kanakoudis 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. This argument holds that, regardless of 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 address in this study by examining minimum charges by municipal water utilities as the amount that households are obliged to pay 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, fixed costs from water losses in their network.

Finally, we introduce a spatial aspect to our models that explain water and minimum access charges. In addition, 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 within a spatial framework which are not adequately captured by independent variables.

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 for water provision. The next two sections cover: previous literature related to the economy of water along with empirical models, methods, and data utilized in this research. In the last two sections, we provide the results and then conclude with a discussion of the implications from this research.

2. Literature Review

Among the studies on water issues include: pricing and costs, utility ownership and efficiency, utility regulatory policies, and social equity. We will focus on these issues in separate sub-sections below.

2.1. *Water pricing and costs*

Goldstein (1986) argued that potable water is an inexpensive, virtually limit-less resource in many areas of the United States. According to Goldstein, accessibility and availability of water supplies are reasons why water cost is not a substantial concern in the US. After 30 years of changes in availability of water resources, the Goldstein argument of limit-less water supplies is questionable (e.g., Boyer *et al.* 2015 note examples in the western US), but his main recommendation of setting water charges in a way that reflects the full cost of providing water is still accurate and valuable. From Feigenbaum and Teeples (1983), who recommend a hedonic cost function for water provided by public versus private, to Bae (2007), who investigates institutional factors influencing water pricing systems, there is a considerable amount of research evaluating water pricing in the US. These pricing structures involve different systems of either a uniform block rate, decreasing block rate, increasing block rate, or a combination of increasing and declining block rates.

While Renwick and Archibald (1998) find that price-based policies are as effective as non-price policies, there is a clear trend in water conservation policies towards volumetric charging (Inman and Jeffrey 2006; Randolph and Troy 2008; Millock and Nauges 2010; Polycarpou and Zachariadis 2013). Baerenklau *et al.* (2014) provides 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. Sanchez-Martinez and Rodriguez-Ferrero (2016) argue that natural hydrological conditions require application of complex, integrated and highly developed water management and pricing systems.

Finally, two influential studies for this research include Bae (2007) and Antonioli and Filippini (2001). Bae (2007) examines factors influencing the cost of water provision. He separates influential factors 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 rate structures are the explanatory variables that Bae uses to explain cost variation over a sample of 259 utilities across the US. For monthly residential water charges, positive impacts on cost are found for variables concerning the volume of water sold, use of increasing block rates, long-term utility debt, water loss, implementation of prior appropriation doctrine, and providing other infrastructure services. Variables with negative impacts include ground water as a source, water treatment capacity, daily water production, and a combined bill with other services. Antonioli and Filippini (2001) recommend controlling for geographical and morphological variables in cost model in order to achieve more accurate results.

2.2. *Water efficiency, ownership, and utility regulation*

Among water efficiency and ownership studies, Teeples and Glyer (1987) estimate three cost models examining water delivery systems to compare ownership efficiency. The authors find that as specification improves, differences between public and private water provision reduce to insignificance. Renzetti and Dupont (2004) find the same results in their study. They emphasize a lack of evidence for differences in performance of public versus private utilities. Also, Bel *et al.* (2010) find there is no empirical evidence that private ownership is more efficient than public ownership utilities. Finally, Carvalho *et al.* (2012) points out that this result is not surprising due to a wide range of different circumstances in each case study.

As mentioned by other water economists, Savenije (2002) 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. In particular, residential water supply is considered a natural monopoly (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. To deal with derived market failure, governmental regulation is required to control the monopoly structure of the water market (Guerrini *et al.* 2011; Pahl-Wostl 2015; Suárez-Varela *et al.* 2017; Araral *et al.* 2017).

2.3. *Water and equity*

Efficiency and equity tradeoffs are a well-defined topic within the foundations of welfare economics (Boadway 1976; Zajac 1978; Le Grand 1990; Kritikos and Bolle 2001). The trade-off between efficiency and equity is considerable when there is a high level of fixed cost of providing services in markets such as those for energy, water, and transportation (Borenstein and Davis 2012). Studies that investigate equity and efficiency in water supply include Bakker (2001), García-Valiñas (2005), and Porcher (2014). Bakker (2001) discusses economic equity versus equalization in water policy. Distinguishing between these two concepts, he explains that based on an equity principle, users should be charged according to their ability to pay. Following Bakker, García-Valiñas (2005) uses the same equity argument to propose a tariff rate which achieves efficiency, equity, financial aspects, and/or public acceptability and transparency. The author controls for water supplied, labor and capital cost, and the length of the pipeline. Porcher (2014) discusses the effects of rebalancing water rates from current tariff to Coasian tariffs in France. The result is a lower bill for consumers and strong distributional consequences.

Water affordability has gained growing attention in recent years (Mack and Wrase 2017; Komarulzaman 2017; Teodoro 2018; Vanhille *et al.* 2018; Wutich *et al.* 2017). The Organization for Economic Co-operation and Development recommends that water bills do not exceed 3–5% of annual household income (OECD 2003 2010). Bithas (2008) argues that increasing block rates do not promote social equity and recommends the number of members in each household be considered in setting water cost. Finally, the 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.

3. Models and Methods

As motivated by Bae (2007), the general form of a model that explains variations in water charges to customers from the *i*th municipal water utility includes four categories of variables that influence the cost of water provision:

$$WC_i = f(Q_i, In_i, En_i, Ge_i), \tag{1}$$

where (WC) is the water charges for a fixed volume of water that customers pay in return for provision of water; (Q) reflects the quantity of water sold by the water utility; (*In*) is a vector of institutional and cost of providing service characteristics of water utilities; (*En*) is an index of water quality provided by the utility; and (*Ge*) is geographical characteristics of the area served by the utility.

As described in the introduction, the WC variable reflects the cost to a residential consumer from consumption of 4,500 gallons of water. This charge represents a consistent water quantity across municipal water utilities and denotes an average cost faced by residential customers. Following Kim (1987), Kim and Clark (1988), Fabbri and Fraquelli (2000), Mizutani and Urakami (2001), 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 distinguishes between output scale and network scale effects (economies of size and scale). Sold water and sold water per capita reflect different (although related) issues of economies of size and scale aspects for municipal water utilities. Also, inclusion of sold water better accounts for water purchases by surrounding communities and public service districts that impact the volume of water produced by the utility.

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 (riparian rights versus prior appropriation), different ownerships for water supply (public water versus private water systems), and different pricing mechanisms (uniform rates, increasing block rate, or decreasing block rates). Our observations are within a single state, consisting of only municipal water utilities where more than 80% follow a declining block rate structure. Since there is limited heterogeneity in block rates, our model does not control for this variable.

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
Ground water as source	Institutional
Violations (number in 2014)	Water quality
Elevation difference (ft.)	Geographical
Average slope (%)	Geographical
Population density (person/sq. mile)	Geographical

The water quality category includes a variable that reflects water quality violations experienced by utilities. For the 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 considered in each category.

Based on Eq. (1) and the variables described above, an empirical equation for water charges is written as:

$$\begin{aligned}\mathrm{WC}_i = {} & \beta_0 + \beta_1 \mathrm{Line}_i + \beta_2 \mathrm{Sold}_i + \beta_3 \mathrm{Sold}_i^2 + \beta_4 \mathrm{Sold\ PC}_i + \beta_5 \mathrm{SoldPC}_i^2 + \beta_6 \mathrm{Debt}_i \\ & + \beta_7 \mathrm{Loss}_i + \beta_8 \mathrm{Ground}_i + \beta_9 \mathrm{Population\ D}_i + \beta_{10} \mathrm{Population\ D}_i^2 \\ & + \beta_{11} \mathrm{Violation}_i + \beta_{12} \mathrm{Elevation\ Dif}_i + \varepsilon_i. \end{aligned} \tag{2}$$

The error term (ε_i) is assumed to comply with the BLUE standard assumptions of expected value equal to zero, homoscedasticity, independently distributed and not correlated with other error terms or the independent variables. However, as pointed out by Guyomard and Vermersch (1989) and Filippini (1996), estimation of a translog variable cost function with a high number of explanatory variables can lead to multicollinearity problems. Thus, we evaluate 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. A total of 10 different specifications are estimated with different functional forms or combinations of independent variables. These specifications are evaluated with adjusted R^2, Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn criteria to select the best model specification. The first six models have a linear functional form and the remaining four are in log–log form. A Davidson–MacKinnon J test is applied to choose between linear and log–log model specifications.

Our approach here is to initially estimate a non-spatial water charges model and then control for spatial spillovers by estimating another model in a spatial framework. According to LeSage and Pace (2009) and Elhorst (2014), non-spatial econometric estimation is based upon observed values being independent of location with no correlation between neighbors. 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 considered to be independent of observations at other locations, i.e., $E(\varepsilon_i\varepsilon_j) = E(\varepsilon_i)E(\varepsilon_l) = 0$.

However, in many cases, this independence assumption is not applicable so that observations at 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:

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

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

where the dependent variable in neighbor j influences the dependent variable in neighbor i and vice versa. When the spatial component (whether this component is from the dependent variable, control variables, or the error term) is statistically significant, the coefficients estimated by non-spatial model may be biased. Also, variances may be non-efficient (Griffith 2005; LeSage and Pace 2009). Accordingly, statistical tests (t-test and F-test) may be invalid, leading researchers to interpret their results improperly.

After examining spatial dependency of our dependent variable with a Moran's I test[1] (Moran's i index = 0.113, p-value = 0.030), this result shows spatial dependency and the need to apply spatial econometrics modeling. There are five possible spatial models. The first is a Spatial Autoregressive lag model (SAR) as shown in Eqs. (3) and (4). Next, a Spatial Error Model (SEM) assumes dependency in error term. A SLX model (Spatial Lag of Explanatory variables) assumes that only explanatory variables play a direct role in determining dependent variables. Lastly, a Spatial Durbin Model (SDM) includes spatial lags of explanatory variables as well as the dependent variable, while a Spatial Error Durbin Model (SDEM) includes these lags along with spatially dependent disturbances.

To observe dependence between neighboring municipal water utility observations, spatial econometrics models differentiate between direct and indirect effects. Direct effects show how changes in an explanatory variable for the ith utility

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

influences the ith utility's dependent variable. Indirect effects illustrate the effects of an explanatory variable in jth utility on ith utility's dependent variable.[2] LeSage (2008) argues that since the impacts of the explanatory variable are different among observations, it is desirable to have a measurement of overall and average impacts. These measurements can be divided into the concepts of average direct, indirect, and total effects (LeSage and Pace 2014).

Parameters in a general linear regression are interpreted as a partial derivative of the dependent variable respect to the explanatory variable. An assumption of independence between variables and between observations serves as the bases for this interpretation. In a spatial model, however, interpretation of the parameters becomes more complicated. As numerous authors (LeSage and Pace 2009; Anselin and Le Gallo 2006; Kelejian *et al.* 2006; Kim *et al.* 2003; Le Gallo *et al.* 2003) argue, a model with a spatial lag of the dependent variable requires special interpretation of the parameters. Elhorst (2014) calculated the direct, indirect, and the total effect in a general nesting spatial model as:

$$Y = (I - \delta W)^{-1}(X\beta + WX\theta) + R, \tag{5}$$

where W is the spatial weight matrix, δ is called the spatial autoregressive coefficient, θ represents a $K \times 1$ vector of fixed but unknown parameters to be estimated, and R represents the intercept and error terms.

The matrix of partial derivatives of the expected dependent variable with respect to changes in explanatory variables becomes:

$$\begin{aligned} \left[\frac{\partial E(Y)}{\partial x_{1k}} \cdot \frac{\partial E(Y)}{\partial x_{Nk}}\right] &= \begin{bmatrix} \dfrac{\partial E(y_1)}{\partial x_{1k}} & \cdot & \dfrac{\partial E(y_1)}{\partial x_{Nk}} \\ \cdot & \cdot & \cdot \\ \dfrac{\partial E(y_N)}{\partial x_{1k}} & \cdot & \dfrac{\partial E(y_N)}{\partial x_{Nk}} \end{bmatrix}, \\ &= (1 - \delta W)^{-1} \begin{bmatrix} \beta_k & w_{12}\theta_k & \cdot & w_{1N}\theta_k \\ w_{21}\theta_k & \beta_k & \cdot & w_{2N}\theta_k \\ \cdot & \cdot & \cdot & \cdot \\ w_{N1}\theta_k & w_{N2}\theta_k & \cdot & \beta_k \end{bmatrix}, \end{aligned} \tag{6}$$

where w_{ij} is the (i, j)th element of W. Every diagonal element of the partial derivative matrix in Eq. (6) shows the direct effect while the indirect effects are shown by every off-diagonal element. Since the direct and indirect effects are unique for each observation, LeSage and Pace (2009) propose to report the

[2]For more information see LeSage and Pace (2014) and LeSage (2008).

summary indicators (the average of the diagonal elements for the direct effect and the average of either the row sums or the column sums of the off-diagonal elements for indirect effects). Since θ in a SAR model is equal to zero, indirect effect would be equal to the off-diagonal elements of $(1 - \delta W)^{-1}\beta_k$

The weight matrix (W) quantifies the connections between regions. Elhorst (2014) names the weight matrix as a tool to describe the spatial arrangement of geographical units in the sample. There are variety of units of measurement for spatial dependency such as neighbors, distance, and links (Getis 2007). Our spatial weight matrix is based on the distance between municipalities and our applied seven nearest-neighbors weight matrix.[3] Spatial econometric models are estimated using software codes provided by Dr. Donald Lacombe.[4]

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. Kanakoudis and Tsitsifli (2014) argue that the determination of the fixed charge should 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:

$$MMC_i = f(WC_i, SE_i, SM_i, CS_i, WL_i) \tag{7}$$

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

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

[3]While LeSage and Pace (2010) argue that the configuration of the spatial weight matrix matters very little, a seven nearest neighbors weight matrix maximizes the log-likelihood for the spatial model.
[4]Available at: http://myweb.ttu.edu/dolacomb/matlab.html.

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 *et al.* 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 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 (10,000–50,000 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 those from water losses, influence the minimum water charge.

The empirical model for minimum monthly access charges is:

$$\mathrm{MMC}_i = \beta_0 + \beta_1 \mathrm{WC}_i + \beta_2 \mathrm{PCI}_i + \beta_3 \mathrm{SR}_i + \beta_4 \mathrm{HO}_i + \beta_5 \mathrm{SM}_i + \beta_6 \mathrm{CS}_i + \beta_7 L_i + \varepsilon_i, \tag{8}$$

where (PCI) is average per capita income; (SR) is the percentage of households with one or more person above 65 years old; and (HO) is the percentage of households who own a home. To avoid a simultaneity issue, predicted water charges from Eq. (2) are utilized for WC since both water charges and minimum charges are proposed simultaneously by water utilities to the WV PSC.

Since education, percent below poverty, and income variables are highly correlated, we conducted robustness checks by examining different combinations of these variables in model specifications. We examine four different regression models and based on adjusted R^2, AIC, SIC, and Hannan-Quinn criteria, the best model specification is chosen.

4. Data

Data for this research are primarily based on the annual reports submitted to the WV PSC by municipal water utilities. These annual reports are available through the WV PSC website[5] and collected for 2014. These reports contained numerous missing values — mostly for total treatment capacity, total main line, total long

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

term debt, and water source. According to the WV PSC, there is no obligation for utilities to provide the information in their annual report. Thus, additional data were gathered through email and phone calls to utility personnel about missing data or when information in a report seems questionable.

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 obtained from an annual report of Environmental Engineering Division of the WVBPH: (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. A dummy variable is employed due to the large number of zero violations — out of 125 observations, 72 municipalities did not have any reported violations in 2014. 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 database. For local governance, historically, most municipalities in West Virginia have implemented a mayor-council type of government (Brisbin *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.

Tables 2 and 3 show the data summary statistics[6] 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, 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

[6]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.

Table 2. Summary Statistics of Variables Used in the Water Charge Model ($n = 125$)

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	+
Ground water 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	+

two topographic variables: difference between maximum and minimum elevation and average percent slope (Reznik *et al.* 2016). We expect both to have negative coefficients — the more changes in topography, the higher the cost of providing water due to higher costs of water transmission.

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

Table 3. Summary Statistics of Variables Used in the Minimum Monthly Access Charge Model ($n = 125$)

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	N/A	0	1	–
Water loss (%)	24.59	17.23	0	92.32	+

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.

5. Results

We estimate regressions using WC and MMC as dependent variables with institutional, governmental, geographical, environmental, and socioeconomic factors serving as independent variables. Variables that are highly correlated with the number of customers (network length and debt) are converted to per capita to avoid multicollinearity. For the water charges model, all specification criteria (adjusted R^2, AIC, SIC, and Hannan-Quinn criteria) show models with violations and elevation difference variables as the best for both linear and log–log specifications. The Davidson–MacKinnon J test resulted in selection of a linear specification with variables not transformed into log values.[7] No multicollinearity problems are observed in the linear model specification.[8]

For the spatial model, we choose the most representative weight matrix for the data by testing for 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 statistic guides us to our particular specification (Kalenkoski and Lacombe 2013).

To examine spatial correlation among observations, we utilize five different spatial models (i.e., SAR, SEM, SLX, SDM, and SDEM). Table 4 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 A. 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.

[7]The estimated coefficient for predicted values from the log-log model in the linear model is 0.10 (p-value $= 0.717$) while the estimated coefficient for the predicted value from the linear model in the log-log model is 1.04 (p-value $= 0.000$).

[8]Dropping sold water, per capita sold water, and population density variables from the regression model one variable at a time does not substantially impact the other coefficient estimates in the resulting regressions. These regression model results are available upon request from the authors.

Table 4. Water Charges Model Results for OLS and SAR Estimations ($n = 125$)

Variable	OLS Coefficients	SAR Direct Effect	SAR Indirect Effect	SAR Total Effect
Network length pc	5.20	5.15	1.87	7.03
	(0.096)*	(0.087)*	(0.442)	(0.131)
Sold water (000)	−8.82	−8.33	−2.15	−10.48
	(0.282)	(0.285)	(0.544)	(0.315)
Sold water^2 (000)	0.0007	0.0004	0.00007	0.0005
	(0.859)	(0.915)	(0.992)	(0.936)
Sold water pc	−126.40	−125.33	−44.37	−169.71
	(0.006)***	(0.004)***	(0.368)	(0.026)**
Sold water pc^2	147.79	146.86	51.88	198.75
	(0.006)***	(0.004)***	(0.366)	(0.025)**
Debt pc	1.84	1.84	0.65	2.50
	(0.002)***	(0.001)***	(0.347)	(0.015)**
Water loss	0.05	0.05	0.02	0.07
	(0.281)	(0.234)	(0.511)	(0.273)
Ground water	−5.11	−4.83	−1.61	−6.45
	(0.008)***	(0.008)***	(0.339)	(0.020)**
Population density (000)	−10.01	−9.87	−2.59	−12.46
	(0.000)***	(0.000)***	(0.336)	(0.009)***
Population density^2 (000)	0.002	0.002	0.0004	0.0022
	(0.002)***	(0.001)***	(0.346)	(0.015)**
Violation	0.17	0.15	0.04	0.20
	(0.323)	(0.346)	(0.590)	(0.378)
Elevation difference	−0.006	−0.005	−0.001	−0.007
	(0.110)	(0.126)	(0.432)	(0.157)
Constant	55.54	—	—	45.45
	(0.000)***			(0.000)***
	Adj. $R^2 = 0.32$	Adj. $R^2 = 0.34$		
	$F_{12,112} = 5.91$			
		$\rho = 0.23$		
		p-value $= 0.001$		

Note: p-values in parenthesis.
pc = per customer.
*Significant at 10%; **significant at 5%; ***significant at 1%.

With a statistically significant ρ value in the SAR model, the OLS coefficient estimates are likely biased and presented in Table 4 only for a comparison with the magnitude of the direct effects from the SAR model. The water charges model has direct effect with p-values below 0.05 for the variables: sold water per capita; total debt; ground water as a water source, and population density. The network length variable has a direct effect with a p-value under 0.10, while water loss, elevation difference, and violation variable coefficients have p-values much above 0.05

(Table 4). Our expectations for the elevation difference and violation variables are not met by this model; however, their *p*-values are all above 0.10.

To interpret the direct effect results, a one person increase per square mile will decrease the water charge by $0.01 per 4,500 gallons. Based on the quadratic form of population density, charges decrease up to a density of 5,000 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 ground water as a primary water source reduces this charge by $4.83, and an increase of one mile in main line length per customer will increase this charge by $5.15.

While none of the indirect effects have *p*-values even close to 0.10, the total effect impacts in the SAR model increase the overall magnitude of impact on water charges for each variable. For example, ground water 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, the best model specified for minimum monthly access charges includes variables for households with one or more residents over 65 and per capita income (Table 5). This model is examined for spatial impacts with the same procedure as the water charge model to choose the most appropriate weight matrix. Similar to the water charges model, the seventh nearest neighbor weight matrix has the highest log-likelihood. The results of the SAR and SEM estimations (the only two spatial models with statistically significant spatial components) are presented in Table 5. The results for the other three spatial models are presented in Appendix B.

Interpreting the spatial model impacts, only predicted water charges impact minimum monthly access charges with *p*-values below 0.05. These minimum monthly access charges incorporate from between 33% and 40% of the municipal utility's 4,500 gallon charge. All other variables, including the socioeconomic variables, have impacts with *p*-values well above 0.10. Overall, the results of these models show that socioeconomic factors within municipal populations do not contribute to equity considerations explaining variations in municipal utility minimum monthly access charges.

Water charges have positive indirect effects on the minimum monthly access charges so 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 in the SAR model,

Table 5. Minimum Monthly Access Charge Model Results for OLS, SAR, and SEM Estimates ($n = 125$)

Variable	OLS Coefficients	SAR Direct Effect	SAR Indirect Effect	SAR Total Effect	SEM Coefficients
Predicted water charge	0.39 (0.000)***	0.33 (0.000)***	0.11 (0.077)*	0.44 (0.000)***	0.39 (0.000)***
Household with one or more older than 65	0.04 (0.638)	0.03 (0.524)	0.01 (0.589)	0.04 (0.534)	0.04 (0.649)
Per capita income	−0.04 (0.658)	−0.04 (0.710)	−0.02 (0.759)	−0.06 (0.720)	−0.028 (0.746)
Home ownership rate	0.06 (0.264)	0.04 (0.238)	0.01 (0.368)	0.05 (0.259)	0.06 (0.230)
Class II municipalities	−1.20 (0.645)	−1.68 (0.647)	−0.68 (0.708)	−2.37 (0.659)	−0.38 (0.824)
Strong Mayor	−4.55 (0.095)*	−4.62 (0.118)	−1.70 (0.276)	−6.33 (0.099)*	−4.04 (0.115)
Water loss	0.01 (0.100)*	0.006 (0.855)	0.001 (0.898)	0.007 (0.864)	0.001 (0.959)
Constant	1.02 (0.823)	—	—	−5.25 (0.31)	1.51 (0.736)
	Adj. $R^2 = 0.19$		Adj. $R^2 = 0.20$		Adj. $R^2 = 0.23$
	$F_{7,117} = 5.19$				
			$\rho = 0.34$		$\lambda = 0.31$
			p-value $= 0.007$***		p-value $= 0.022$**

Note: p-values in parenthesis.
*Significant at 10%; **significant at 5%; ***significant at 1%.

none of the variable coefficients other than predicted water charge in Table 5 show evidence of statistical significance.

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 (Antonioli and Filippini 2001). As discussed earlier, the main goals of this study are to: (1) estimate the influences of water quantity and quality as well as institutional and geographic factors on water charges, and (2) estimate the determinants of minimum monthly access charges across municipalities in West Virginia. Our estimation of the water charge model shows 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 an influential factor to explaining water charges. The addition of a geographic variable did not explain variations in water charges.

From our model results, ground water 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 ground water quality with source water protection programs. According to the US Environmental Protection Agency, states, local governments, and utilities all play important roles in water protection programs. In West Virginia, implementation of wellhead protection programs began in the early 1990s 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 this ground water protection. Allowing for a \$5 saving for each 4,500 gallons of use and over 240,000 households in West Virginia served by municipalities using ground water, an annual cost savings of \$3.6 million in water charges is computed. These savings are based on comparisons of using other water sources by municipal water utilities.

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 in our data and 4,500 gal of water use monthly, utility debt currently 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,[9] different organizations provide long-term fixed low-interest loans to rural areas and low-income communities to help them to improve 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, both size and scale impacts are still found in small municipal utilities.

[9]http://efcnetwork.org/wp-content/uploads/2016/07/WV-Water-Wastewater-Funds-2016.pdf

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 statistically influence indirect impacts, water charges in the minimum monthly access charge model has 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 a “strong” mayor governing system are assessed lower minimum charges than other municipalities. Overall, minimum charges are closely related to water charges incorporating just over one-third 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 by the water charge and divided by the average household income. On average, West Virginia households pay far below the OECD standard of 3–5% of household income for water. Our results indicate that the average share of water costs across West Virginia households with municipal water utilities is about 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 access charges for water.

Finally, this research raises few issues with affordability of current municipal water charges. However, Mack and Wrase (2017) project affordability issues that could occur with future water rate increases of 6% and 41%. These projected increases are based upon observed water rate increases since 2010. If such future water rate increases do occur, this will leave the state of West Virginia with the highest percentage of at-risk census tracts (46%) of any state in the nation for households unable to afford water bills, primarily due to the prevalence of low-income and elderly households in southern and central parts of the state. Their research raises potential future concerns about the continued affordability of water and the financial viability of municipal utilities providing service to areas with numerous low-income households.

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Appendix A. Estimation Results for Water Charges SEM, SDM, SLX, and SDEM Models

Table A.1

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)

Table A.1 (*Continued*)

Variable	SEM	SDM	SLX	SDEM
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)
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^2	0.37	0.44	0.44	0.44
Number of observations = 125				

Note: *p*-values in parenthesis.
*Significant at 10%; **significant at 5%; ***significant at 1%.

Appendix B. Estimation Results for Minimum Water Charge SEM, SDM, SLX, and SDEM Models

Table B.1

Variable	SDM	SLX	SDEM
Predicted water charge	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	−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	−1.02	−1.06	−1.20
	(0.135)	(0.658)	(0.609)
SM	−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)

Table B.1 (*Continued*)

Variable	SDM	SLX	SDEM
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)	(0.888)
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^2	0.28	0.28	0.29
Number of observations = 125			

Note: *p*-values in parenthesis.
*Significant at 10%; **significant at 1%.

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