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Cost Plus

Estimating Real Determinants of Water and Sewer Bills

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This article tests the importance of cost, demand, institutional, and geographic factors on the bills that consumers pay for water and sewer service in North Carolina and the pricing signals that utilities send to customers. The authors apply spatial regression models to test whether other factors besides costs drive rate-setting practices. Results indicate that cost factors, operating ratio, temperature, the application of "outside" rates, and utilities' primary importance on affordable rates affect combined water and sewer bills at average levels of residential consumption. The study also finds that bills are significantly and positively correlated to bills paid in nearby utilities. Community income and the percent of customers below the poverty line are weakly associated with combined bills. However, utilities facing higher growth rates and those that value conservation are no more likely to send stronger pricing signals than others.

Keywords: *rate-setting practices; water utilities; sewer utilities; United States; local government*

Setting rates for water and sewer services has become a highly diversified, integral function of local and regional governments across the United States. Approximately 60,000 community water systems provide water to 85% of U.S. residents, whereas public sewer systems collect wastewater from nearly 75% of the U.S. population. Taken together, annual revenues from all government-owned and investor-owned water and sewer utilities comprise a US$26 billion industry (Hyman, 1998).

Given the long history of water and sewer supply and the importance of these services to public health and welfare, it comes as no surprise that numerous theoretical treatises and practical manuals have been published on how to set appropriate prices for these services. The capital-intensive nature of the industry has focused considerable attention on the need for government investment and/or ownership and the importance of cost-recovery objectives. Economists and sector practitioners have developed mechanisms for measuring cost functions over time. Moreover, the importance of these essential public services has encouraged others to develop methods of accurately estimating and forecasting their demand functions.

Yet few empirical studies have examined the relative importance of supply, demand, institutional, and geographic characteristics on the actual prices consumers pay for water and sewer service. There is a common assumption that prices reflect a utility's average historical (if not marginal) cost of providing that service at a given level of consumption (demand) because profit is not permitted for government-owned utilities. This assumption may not actually represent how utilities set their prices. Cost factors may not predict rate setting effectively once demand, institutional, and geographic characteristics are taken into account. Institutional ownership and political priorities among public utilities may impact the rate structures selected by communities and bills paid by customers. Utilities may also account for changes in future supply and demand factors when setting existing rates, or pay more attention to what other utilities currently charge for service—neither of which is reflected in traditional cost models.

This article tests the importance of cost, demand, institutional, and geographic factors in the bills consumers pay for water and sewer service in North Carolina. Specifically, it examines the question of whether cost drivers are the only factors influencing rates. The influence of key priorities and policies on utilities' rates is estimated to test the strength of association between policy and the price signals the governing body sends to its residential customers. The next section summarizes conventional economic theory on rate setting and reviews key previous rate surveys, cost and demand function studies, and prior evidence on rate determinants. The "Study Overview and Methods" section describes the North Carolina context, how the authors collected the data, and what are the procedures used to generate bill and price factor estimates. "Model Specification" section demonstrates the models used to specify determinants of water and sewer bills. The last two sections describes the data and their sources, and results, respectively. The final section discusses study implications and avenues for additional research.

Background

A number of studies have discussed the importance of various rate-setting objectives (American Water Works Association [AWWA], 2000; Beecher, Chestnutt, & Pekelney, 2001; U.S. Environmental Protection Agency [USEPA], 2003; Zajac, 1979, 1996). Water and sewer utilities have traditionally been considered classic examples of natural monopoly due to the heavy capital intensity of their services. On average, utilities have invested US$4 to US$5 in capital for every US$1 of revenue (AWWA, 2000). Historically, many utilities have not covered the full cost of replacement capital in rate setting because their institution has not been solely responsible for financing major public infrastructure investment. For example, the U.S. Environmental Protection Agency's Clean Water and Drinking Water State Revolving Funds alone provided nearly US$3 billion in funding to utilities for a variety of capital projects. The price incentive thus encourages managers to generate enough operating revenue to cover short-run operating costs. Over time, this has led utilities to focus on the historical, average operating "expenditures" when setting rates, as opposed to long-term marginal "costs." Utilities have also been accused of failing to include certain assets when establishing the rate base and ignoring the opportunity costs and "scarcity" value of extracting water for future consumers (Hanemann, 2005; Moncur & Fok, 1993).

Prior studies have estimated cost functions for water and sewer utilities. Ford and Warford (1969) and Crain and Zardkoohi (1978) developed an average-cost model using a water production function approach. Feigenbaum and Teeples (1983) argued that this approach is problematic because it often ignores energy and water input factors and it assumes that water quality and delivery costs are consistent across utilities. They opt for a hedonic cost function, which replaces water produced with total utility costs and accounts for other inputs. The authors compared costs of private versus public utilities and found no significant difference in cost functions. A review by Renzetti (1999) further suggested that most studies find that economies of scale or scope exist among water and sewer utilities. Shih, Harrington, Pizer, and Gillingham (2006) confirmed the presence and likelihood of scale economies for smaller water utilities, particularly with respect to capital expenditures.

There is a larger body of literature on estimating residential water demand. These studies frequently estimate demand functions by learning how much individuals consume at different given marginal prices and/or pricing blocks. Organization of Economic Cooperation and Development (OECD; 1987) provided an early survey of this literature. Price and income elasticities of demand are also important outcomes in these studies. Beecher, Mann, Hegazy, and Stanford (1994) meta-review of residential water-demand studies in the United States suggests relatively low price elasticities, ranging from –0.2 to –0.4 (i.e., a 10% increase in price lowers demand by 2%-4%). Fewer studies consider demand for wastewater services, in part because demand of these services is usually driven by the amount of water consumed. One study (Strudler & Strand, 1981) estimates that the average price elasticity for residential sewage service is –0.07, with a range on either side of zero.

The political economy of water pricing has gained more attention as greater consensus has emerged that water should be considered an economic good. Institutional effects have often focused on the question of public versus private ownership. Researchers (Feigenbaum & Teeples, 1983; Renzetti & Dupont, 2003; Wallsten & Kosec, 2005) have found little evidence from operating costs to support the contention that private utilities are more efficient. Comparisons of public institutional types have been limited, although Glennon (2004) described key issues facing rate setting using an example from Tucson, Arizona. Hewitt (2000) has examined why water utilities select specific rate structures, in particular increasing block tariffs in California. Using logit models, she found that utilities were more likely to choose increasing block tariffs over uniform rate structures under the following conditions: (a) location in a warm, dry climate with a longer growing season; (b) limited reliance on debt financing; (c) public ownership; and (d) larger utility size.

There are a number of state and national surveys of water and sewer rates and rate structures (AWWA, 2004; North Carolina League of Municipalities and

UNC Environmental Finance Center [NCLM & EFC], 2005; Raftelis, 2004; USEPA, 2002). These surveys are generally descriptive in nature. Few studies specifically feature prices and their determinants. An early, small sample study of Mississippi (Hollman & Boyet, 1975) used a basic regression model to analyze the association between prices, costs, and financial characteristics. Renzetti (1999) has compared prices and marginal costs for water supply and wastewater treatment and found that municipalities in Canada charged only one third and one sixth of the respective estimated marginal costs. More recently Garcia, Guerin-Schneider, and Fauquert (2005) have looked at price determinants in France. Using a one-way fixed-effects model, they found that local governments' different operating and negotiation strategies with private operators significantly impact water prices as a result of bidding procedures even after controlling for cost and geographic factors.

Study Overview and Methods

In the state of North Carolina, rate-setting authority for government-owned and not-for-profit utilities resides with local governing boards. State statutes provide minimal guidance and restrictions on how rates and rate structures are to be determined, resulting in a wide range of rate-setting practices throughout the state. This situation represents an unregulated market for rate setting among government-owned systems. By contrast, for-profit utilities that bill households directly for water and sewer service must have all rates and fees approved by the state Utilities Commission.

All units of government in North Carolina must submit annual financial information (but not rate information) to the state's Local Government Commission (LGC) within the Department of State Treasurer. Not-for-profit utilities are not required to submit financial data to a centralized state source, although recent efforts have attempted to collect some information from the largest not-for-profit utilities. Local government and not-for-profit utilities with financial data were selected for this study to estimate the effects of various factors on rates in an environment with almost no regulation on rate-setting practices. These utilities are relatively active in setting and updating their residential rate structures, with 80% of a large sample reporting reviewing their rates annually, 50% raising their rates in the last fiscal year, and 72% of municipalities increasing their water rates above the rate of inflation since 1986 (NCLM & EFC, 2006).

The North Carolina League of Municipalities (NCLM) identified 412 water and/or sewer municipalities in 2005 in the state. Using the list of counties, sanitary districts and water/sewer authorities which reported water/sewer financial data to the LGC in June 2004, 103 "active" nonmunicipal, government-owned utilities were also identified (NC State Treasurer, 2006). In addition, 27 not-for-profits serving a total of over 300,000 people were identified from data collected in 2003 by the consulting teams working on a statewide water-planning effort referred to as Water 2030 (NC Rural Center, personal communication, June 18, 2005). In 2006, these 542 utilities were invited to participate in the study. A 12-page questionnaire designed to collect information on rate-setting practices and priorities and system characteristics were mailed and emailed to the water/sewer managers of the 542 utilities (Environmental Finance Center [EFC], 2006). Utilities were requested to submit a copy of their fiscal year 2005-2006 rate sheets when responding to the survey. To increase the number of rate sheets submitted, follow-up phone calls were made to over 100 nonresponding utilities that had provided their rate sheets in the previous year's rate survey.

The rate sheets were studied and entered into a customized database. This research represents, to the authors' knowledge, the first attempt in a study to standardize rate information across hundreds of utilities and automate the process of computing the residential customer charges for water and sewer based on continuous quantities. Previous surveys have computed customer bills by either (a) requiring the respondent of a survey to specify the monthly customer bill for a few (usually three or four) preselected quantities of consumption (e.g., at 0 gallons; 3,000 gallons; and 10,000 gallons), or (b) requesting the rate schedule from a utility so that the researchers would themselves manually compute the customer bill for a few discrete quantities. Due to the nature of rate structures, where rates are often not uniform between two consumption quantities, it is impossible to accurately determine the customer billing between the preselected quantities simply through linear interpolation. Hence, it becomes difficult to compare customer billings at consumption quantities other than those preselected by design—which also complicates analysis on price signals and bill changes for different consumption levels.

By contrast, a model was designed for this study that determines residential bills and facilitates comparisons for any level of consumption. The model computes the water and/or sewer monthly equivalent billing using rates' data and input variables such as the type of bill (water, sewer, or combined), the high or low season (for seasonal rate structures), the bill for customers residing inside or outside the city limits, the meter size of the unit, and the quantity of water billed per month for the household. Once the input variables are selected, the model generates the residential customer billing for any quantity of water selected for all the utilities in the database, standardized on a monthly basis. The average monthly consumption of residential customers for each utility was computed using data collected by the state's Local Water Supply Plans in 2002 (North Carolina Department of Environment and Natural Resources [NCDENR], personal communication, February 22, 2005). Unfortunately, more recent attempts at collecting average residential consumption data have yielded incomplete or significantly inaccurate data, including the survey from this study (EFC, 2006) and the Water 2030 project (NC Rural Center, personal communication, June 18, 2005).

The monthly residential bill for the average level of consumption for each utility was then linked to supplemental utility and household financial information at the utility level from primary and secondary sources. The monthly bill at the average consumption level for each utility is determined directly from only two factors: the consumption quantity and the prices set by the utility. The purpose of this article is to establish the various factors that affect the monthly bill at the average consumption level through influencing rate-setting practices of the utility managers and/or residential consumption levels for the utility.

Model Specification

A hedonic technique was adopted to determine the relationship between residential water and sewer bills for sets of supply, demand, institutional, and location characteristics. Hedonic models estimate implicit price functions from the characteristics of related products in a particular product class, or:

$$p_y = \mathrm{f}[q_{i1}, \ldots, q_{ij} \ldots, q_{in}]$$

where p_y is the hedonic price and $q_{i1}, \ldots, q_{in}$ is the set of related characteristics. Hedonic models have been applied in areas such as housing markets, labor markets, and recreational goods (Freeman, 1993). Researchers have also used these models in establishing cost functions for water and sewer utilities, as previously mentioned.

Our unit of analysis is at the utility level. The hedonic price in our model is the monthly bill charged to residential customers at the average level of consumption for their utility. We begin with the supply side of the market, as utilities evaluate their rate structures to ensure that average bills meet their expected average costs for the next fiscal year. The model presumes that the bill set by utility i for service j at quantity q ($P_{i,j,q}$) can be described initially as a function of cost characteristics and an error term; that is,

$$P_{i,j,q} = \alpha + \beta C_{i,j,q} + \varepsilon_1 \quad (1)$$

in which the hedonic price is the total monthly bill charged to residential customers (including fixed and volumetric charges), and $\mathbf{C}_{i,j,q}$ is a vector of factors that drive the cost of service j at quantity q for utility i. Services include water, sewer, or combined water and sewer services.

Cost factors ideally would include the actual operating, maintenance, and capital expenses for providing the service and quantities specified. However, cost data are very difficult to obtain, especially from small systems which frequently do not maintain accurate accounts. Even the largest and most sophisticated utilities are usually unable to compute their marginal costs, which are required to determine the costs required to provide different quantities of service. Instead, researchers often use data on cost drivers as a proxy for costs of service, which are easier to report and often available from secondary sources. Cost drivers are factors that influence costs through direct means (such as water sources requiring additional treatment processes), indirect means (including purchasing treatment services from another utility) or through economies of scale (e.g., utility size and population density). Cost determinants considered in this analysis include (a) utility size, measured by total annual production of water and sewer; (b) total long-term debt (an indicator of capacity and repayment); (c) water source (groundwater or surface water); (d) purchased water system (or self-treating water system); (e) a water source and purchased water system–interaction term,; (f) treated wastewater system (or contracting wastewater treatment by another utility); and (g) population density of the municipality or county. We tested multiple specifications and found that the log-linear specification best represented the production function of the sample of utilities. Estimating how various factors affect the bill of water and sewer service at the average level of consumption is consistent with utility practice of adjusting the rates each year by changing bills with the average level of consumption in mind.

A second model introduces hypothesized demand factors into the bill equation; that is,

$$P_{i,j,q} = \alpha + \beta_1 C_{i,j,q} + \beta_2 D_{i,j,q} + \varepsilon_2 \quad (2)$$

Demand factors of the community being served by the utility, $\mathbf{D}_{i,j,q}$, considered to influence the bill indirectly through the price set and quantity consumed include (a) median household income of the community, (b) percent of residents in poverty, (c) median age of homes in a utility's service area, (d) percent of elderly residents, (e) percent of owner-occupied homes, (f) 30-year normal mean temperature, and (g) 30-year normal mean annual precipitation. The last two variables are believed to influence both cost and demand functions. We maintained the median household income, percent poverty, median age, percent elderly, temperature, and precipitation figures in their linear form for consistency with the log-linear production function, and verified that the specification was the most efficient. An *F* test determines whether the joint set of demand factors influence the hedonic price. Interpretation of the demand factor coefficients will determine their influences, whereas the cost factor coefficients and significance tests examine the robustness of the cost–price relationship.

A third model type incorporates institutional and location factors; that is,

$$P_{i,j,q} = \alpha + \beta_1 C_{i,j,q} + \beta_2 D_{i,j,q} + \beta_3 I_{i,j} + \varepsilon_3 \tag{3}$$

An iterative approach is adopted in developing this model. Although all of the cost factors appear in this model, only the subgroup of demand-side characteristics that are jointly significant is included in the third model to maximize efficiency. Institutional factors include (a) ownership type, (b) whether the utility uses different rates for residential customers living outside the municipal/local government boundaries, (c) whether the utility has different rates for nonresidential customer groups, (d) whether the utility received state grant funding from the 1998 North Carolina Water and Sewer Infrastructure Bond, (e) the ratio of operating revenues to operating expenses, and (f) the responding utility's most important rate-setting priority (cost recovery, affordability, economic development, or conservation). These factors vary by service and utility and are expected to affect the monthly bills by influencing the price of the services.

A final model type accounts for the location of the utility along with the cost drivers and the relevant demand and institutional variables. Two versions of this form are estimated by varying the location variables. The first, Model 4, includes mutually exclusive river basin dummy variables that account for differences in water quality and wastewater treatment regulations. Sensitive river basins in North Carolina face more stringent discharge limits on wastewater, requiring additional treatment (and expense) by sewer utilities discharging into these river basins.

$$P_{i,j,q} = \alpha + \beta_1 C_{i,j,q} + \beta_2 D_{i,j,q} + \beta_3 I_{i,j} + \beta_4 \text{Basin}_i + \varepsilon_4 \tag{4}$$

The second version of this model accounts for spatial autocorrelation (i.e., the possibility that a utility's rate is more strongly correlated to its neighboring utilities' rates than to others in the state). A Moran's I global test of autocorrelation first determines whether spatial autocorrelation among monthly bills exists. Spatial diagnostics are then used to decide whether to incorporate spatial lag (the possibility that a utility's bill is correlated with factors from other utilities) or spatial error (the likelihood that unobservable differences account for clustered values of adjacent utility bills) in the model specification (Anselin, 1992). Due to the presence of regional variables, this model includes a spatial term to classify autocorrelations among neighboring utilities bills (ρ) as well as an error term for cross-region effects (ε_5):

$$P_{i,j,q} = \alpha + \beta_1 C_{i,j,q} + \beta_2 D_{i,j,q} + \beta_3 I_{i,j} + \rho + \varepsilon_5 \tag{5}$$

In addition, we use other models to examine the influence of specific rate-setting priorities and utility policies, $X_{i,j,q}$, as determined by the utility managers, on the bills charged to customers at average and other levels of consumption, controlling for other factors. We specified this model based on Model 5 (the spatial lag model), which demonstrated the best goodness of fit. The issues are mentioned below.

$$P_{i,j,q} = \alpha + \kappa_1 X_{i,j,q} + \beta_1 C_{i,j,q} + \beta_2 D_{i,j,q} + \beta_3 I_{i,j} + \rho + \varepsilon_6 \tag{6}$$

- Future Growth: $X_{i,j,q}$ is set equal to the expected 5-year growth of the service population of the utility to determine whether utilities experiencing higher population growth charge higher combined logged bills for customers at the average level of consumption to pay for new service extensions and infrastructure upgrade.
- Affordability: Here $X_{i,j,q}$ represents a dummy variable indicating whether managers cited affordability as a significant influence in their rate-setting practices. We tested this affordability premise to

Table 1
Summary of Hypotheses for Hedonic Price and Differential Price Models on the Combined Water and Sewer Residential Bills

Independent Variable	Factor Category	Predicted Effect	Reason
Annual production amount	Cost	Negative	Larger systems have lower unit costs
Long-term debt	Cost	Positive	Higher debt payments
Surface water system	Cost	Positive	Surface water systems require additional treatment, higher infrastructure cost
Purchased water system	Cost	Positive	Paying premium over cost of treatment
Surface water & purchase system interaction	Cost	Positive	Expect highest bills for surface water-purchase systems
Treats own wastewater	Cost	Negative	Not paying premium over treatment costs
Population density	Cost	Negative	Lower unit distribution costs
Median household income	Demand	Positive	Ability to pay increases
Percent impoverished	Demand	Negative	Ability to pay decreases
Median age of homes in community	Demand	Negative	Older towns resist increasing rates
Percent elderly	Demand	Negative	Ability to pay decreases
Percent owner occupied	Demand	Negative	Spread cost on more households directly billed
Mean annual temperature	Demand	Positive	Higher demand, more scarce resource
Mean annual rainfall	Demand	Negative	Lower demand, less scarce resource
Ownership type	Institutional	Varies	Expect municipalities to be lowest
Different rates for customers outside area	Institutional	Negative	Cross-subsidy from outside to inside
Different rates for nonresidential users	Institutional	Varies	Cross-subsidy varies by customer base
Received funds from state infrastructure bond	Institutional	Negative	Costs offset by grant
Operating ratio	Institutional	Positive	Higher revenues being collected
Most important rate-setting priority	Institutional	Varies	Expect lower if affordability is a concern
River basin	Location	Varies	Expect higher in sensitive river basins
Growth in customer base	Demand	Positive	Require higher funds for expansion
Affordability mentioned as significant priority	Institutional	Negative	Maintaining low rates
Conservation mentioned as significant priority	Institutional	Positive	Price disincentive for high consumption

determine whether the utilities adopted rates that significantly lowered bills for customers at the average consumption level as well as for customers consuming less water (3,000 gallons monthly), ceteris paribus. To avoid multicollinearity, the variable indicating affordability as the most important objective in setting rates is omitted from this model.

- Conservation: Three additional models examine whether utilities whose managers cited water conservation as an important influence have water rates that provided greater price incentives to reduce consumption for high-volume customers. The first model tests whether these utilities charged higher logged-water bills for consumption at 15,000 gallons. The second and third models compare the absolute change and the percent change in actual water bills from average-level consumption to high-level consumption (15,000 gallons), respectively.

Table 1 outlines the hypothesized relationships tested in the above models.

Data

We received a total of 333 public utilities that provided data on their rates and rate structures for fiscal year 2005 to 2006. Table 2 describes these utilities based on institutional models and service provided. The 333 sample utilities serve water customers in 321 areas and sewer customers in 273 areas. There were 261 utilities which bill for combined water and sewer services, 251 of which contained data on average residential consumption levels from state Local Water Supply Plans. The combined water and sewer bills were computed for each of these utilities and standardized by billing period and measurement units. Information on whether municipalities charge different rates for customers living inside and outside city limits was obtained directly

Table 2
Number of Participating Utilities With Rates Data for FY 2005-2006

Institutional Arrangement	Serves Water and Sewer	Serves Water Only	Serves Sewer Only	Total
Municipality	248	20	7	275
County/District	10	21	1	32
Metropolitan district/Authority	2	1	1	4
Sanitary district	1	4	3	8
Not-for-profit	0	14	0	14
Total	261	60	12	333

from the rate sheets. All models in this article are estimated using rates charged to customers with service boundaries (i.e., "inside" rates).

Data on system physical characteristics as well as the rate-setting practices and priorities of the utilities were collected for 247 of the utilities from the rate practices survey. Utility managers were asked to rate each of the following objectives on whether they were "significant," "somewhat significant," or "not significant" objectives in setting their rates: (a) cost recovery/revenue stability, (b) affordability of residential rates, (c) conservation, (d) fostering business-friendly objectives, and (e) bill simplicity and understandability. Managers were then asked to select the single-most–important objective from the five listed above. Information on whether or not utilities employed different rate structures for nonresidential customers was obtained directly from the survey, whereas systems' physical characteristics were used to supplement and cross-check the variables from secondary sources.

System characteristics data were obtained from EPA's Safe Drinking Water Information System (SDWIS) database and the recent NC Water 2030 study (NC Rural Center, personal communication, June 18, 2005; USEPA, 2005). The SDWIS database identified the sources of water for each utility, from which a dummy variable was created to classify whether the source of water was surface water or groundwater. Utilities that drew water from both surface water and groundwater sources were modeled as surface water systems because these utilities usually require filtration and additional treatment of water than groundwater-only systems. A separate dummy variable indicating whether the utility purchases any portion of their water from another system was also created using data from the SDWIS database. Utilities purchasing treated water from other utilities often pay a price that includes a premium for the service in addition to covering the cost of treatment. The Water 2030 study provided data including (a) the total amount of water produced and wastewater treated in one fiscal year; (b) whether or not the utility treats its own wastewater (or supplies it to another utility and pays for their treatment services); (c) the expected service population in 2005 and 2010 (from which an expected 5-year growth rate was calculated); (d) whether the utility had ever received funding from the State's US$1 billion Water and Sewer Infrastructure Bond, passed by voters in 1998; (e) the river basin in which water intakes were located and which were modeled as 16 mutually exclusive dummy variables; and (f) the latitude and longitude of the centroid of the service area covered by the utility and provided in the form of GIS shapefiles (North Carolina Center for Geographic Information and Analysis [NCCGIA], 2007). Although the number of accounts served and the total water and sewer production in a year are highly correlated, utility size is measured by the latter variable because systems are designed by the expected flow rates, which drive the cost of operation. This was empirically confirmed by observing a greater correlation between the total production and bills charged than the correlation between the number of accounts and bills.

Audited utility financial information for government-owned utilities including operating revenue, operating expenses (including depreciation), and outstanding debt data for fiscal year 2004-2005 were obtained from the state's LGC (NC Treasurer, 2005). These data were the latest recorded data available by the LGC, and present a 1-year lag between the financial reports and when the new water and sewer rates were implemented. This allowed analysis on the influence of the financial condition of the utility in 1 year on the rates set for the following year. An operating ratio was computed by dividing the operating revenue by operating expenses. Expenses here do not include debt service or capital payments.

Socioeconomic and community composition data at the municipal and county levels were obtained from the 2000 U.S. Census. Special district, regional, and not-for-profit utilities serving communities that intersect municipal and county boundaries were assigned the municipal or the county socioeconomic data based on the area where the majority of the service population resides. The data obtained included the median household income, poverty rate, percent of homeownership, percent of homeowners who are above the age of 64 years, the median age of homes in the community, and the population density—computed by dividing total population by the land area of the community.

Table 3
Descriptive Statistics

Variable	*n*	*M*/Percent	*SD*
Utility-level average consumption			
2002 average residential consumption (gallons/month)	304	4,970	1,463
Monthly bills			
Combined water and sewer bill—average consumption	251	US$44.60	US$15.85
Combined water and sewer bill—3,000 gallons	261	US$32.18	US$11.50
Water bill—average consumption	304	US$20.32	US$7.21
Water bill—15,000 gallons	321	US$51.08	US$19.84
Change in water bill (Average to 15,000 gallons)	304	US$30.51	US$15.96
Percent change in water bill (Average to 15,000 gallons)	304	158%	82%
Utility characteristics/Cost drivers			
Daily production amount (1,000 gallons)	247	5,240	15,267
Long-term debt (US$1,000,000)	311	US$12.47	US$58.99
Surface water system	321	60.4%	49.0%
Purchased water system	321	29.9%	45.9%
Surface water and purchase system	321	25.9%	43.9%
Treats own wastewater	291	69.4%	46.2%
Population density (persons/sq. mile of land)	332	907.23	579.43
Demand factors			
Median household income	332	US$33,600	US$11,216
Percent impoverished	332	16.3%	7.4%
Median age of homes in town (years)	332	36.5	9.7
Percent owner occupied	332	65.8%	11.2%
Mean annual temperature (degrees F)	333	59.14	3.08
Mean annual rainfall (inches)	333	49.40	5.22
Institutional factors			
Owned by municipality	333	82.3%	38.2%
Different rates for customers outside area	333	73.0%	44.5%
Different rates for nonresidential users	246	46.3%	50.0%
Received funds from 1998 state infrastructure bond	309	49.8%	50.1%
Most important rate priority—cost recovery	226	77.4%	41.9%
Most important rate priority—affordability	226	20.4%	40.4%
Most important rate priority—conservation	226	0.9%	9.4%
Most important rate priority—other	226	1.3%	11.5%
Operating ratio	311	1.04	0.26
Expected 5-year service population growth	309	16.2%	30.9%
Affordability mentioned as significant priority	243	59.7%	49.2%
Conservation mentioned as significant water priority	233	19.7%	39.9%

Furthermore, 30-year normal mean annual temperatures and precipitation data were obtained for 160 weather stations located across the state from the State Climate Office of North Carolina (2007). The data were collected by the National Oceanic and Atmospheric Administration. The 30-year normal mean temperatures and precipitation data were directly matched against 87 municipal utilities in the state. The average temperatures and precipitation of all the weather stations in each county were used to represent the climate data for 35 utilities whose service areas primarily consisted of counties. Finally, data from the nearest weather station were used for municipal and other nonmunicipal utilities for which a single weather station or aggregated data could not be matched, determined from the latitudes and longitudes of weather stations and of the census places primarily served by the remaining 204 utilities. For these utilities, the average distance between the utility and its matched weather station was 9.4 miles, and the largest distance was 21 miles.

Table 3 summarizes basic descriptive information for the model variables.

Results

The distribution of average consumption levels is shown in Figure 1. The majority of utilities (75%) experienced very similar levels of average residential consumption, ranging between 4,000 and 6,000 gallons/month. Despite the relative

Figure 1
Average Residential Monthly Consumption in 2002 Among 251 North Carolina Utilities Billing for Combined Water and Sewer Services

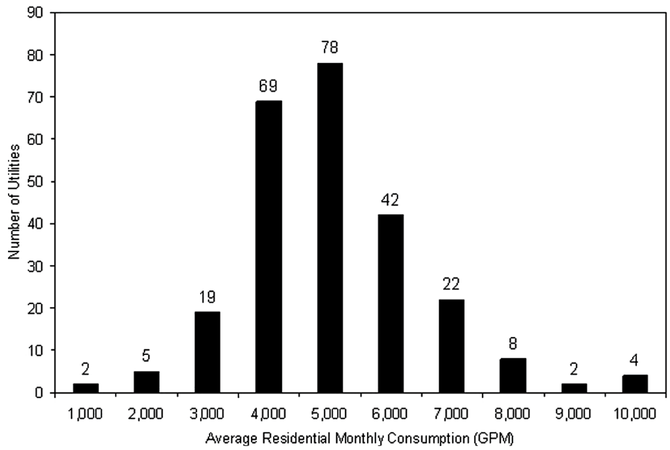

Table 4
Spatial Correlation Results for Combined Bills for the Utilities' Average Levels of Residential Consumption (n = 251 Utilities)

Radius (miles)	Moran's I	SD (I)	z Score	p Value
0-10	.208***	.082	2.582	.005
0-20	.165***	.046	3.686	.000
0-30	.155***	.031	5.183	.000
0-40	.081***	.023	3.646	.000
0-50	.061***	.018	3.581	.000
0-60	.034***	.015	2.500	.006
0-70	.014*	.013	1.439	.075
0-80	.006	.011	0.873	.191
0-90	–.006	.010	–0.228	.410
0-100	–.004	.009	–0.050	.480

*p < .1. ***p < .01.

similarities in average consumption levels, there is wide variation among monthly bills, both at the average consumption level and among the differences in water bills due to changes in consumption, as evidenced by the standard deviations listed in Table 3.

The sample contains a large number of small and medium-size utilities as well as a smaller number of large utilities (in terms of production and debt). The smallest population served in our sample is 200 people, whereas the largest (Charlotte-Mecklenburg Utilities) contains a population of more than 700,000. The majority of utilities uses at least some surface water and treats wastewater. Communities vary among several socioeconomic indicators. Temperature and rainfall also varies, although not to the extent found in other areas of the country.

The vast majority of systems in the sample are municipally owned. Most systems charge "outside rates," whereas half of them charge other rates for nonresidential customers. Almost half of the utilities received at least one grant from the State Water and Sewer Infrastructure Bond since its passage in 1998, although the grant amounts differ substantially. Although most water and sewer managers view cost recovery as their primary rate-setting objective, fewer utilities actually recover their operating costs with operating revenues. Affordability is seen as a significant factor in rate setting by a majority of managers; yet only one fifth believes that conservation policies significantly affect rate-setting decisions on water rates.

Table 4 presents the results of Moran's I global test of spatial autocorrelation of the actual combined water and sewer bills at the average level of consumption. The combined bills are significantly correlated (at a 1% rejection level) within radii up to 60 miles, and the strength of the spatial autocorrelation decreases as the distance increases. Spatial dependence diagnostic tests on the log-linear regressions of combined bills indicated the presence of spatial lag but failed to detect the presence of spatial autocorrelation in the error term. This suggests the need to control for spatial lag in one of the versions of the full model.

Table 5 presents results for the models that consider cost, demand, institutional, and geographic factors. The chi-square statistics for tests of joint significance for each group of factors in the models are shown in Table 6.

As expected, cost drivers impact the bills customers pay for combined water and sewer service. Larger utilities charge lower log–combined bills, whereas those with higher debt pass these costs onto their customers. Utilities that purchase their water pass the additional transaction cost of obtaining this water onto their base. Although the surface water and purchase system–interaction term is negative and statistically significant, the net effect of relying on purchased surface water is positive—reflecting the increased cost of treating surface water at the treatment plant. By contrast, utilities which treat their own wastewater (and do not have to purchase treatment services from a third party) charge their customers a lower combined bill, although the effect is not statistically significant. Population density does not affect combined log bills, possibly due to limitations of

Table 5
Effects of Cost, Demand, Institutional, and Geographic Factors on Logged Combined Water and Sewer Bills at Average Consumption Levels

	(1) Cost	(2) Cost & Demand	(3) Cost, Demand, & Institution	(4) Cost, Demand, Institution, & River Basins	(5) Cost, Demand, Institution, & Spatial Lag
Cost drivers					
Water & sewer sales (MGD)	–.012** (.005)	–0.012** (.005)	–0.013** (.006)	–.011* (.006)	–.011** (.005)
Long-term debt (million $)	.003** (.001)	0.003** (.001)	0.002* (.001)	.002 (.001)	.002* (.001)
Surface water system	.036 (.064)	0.123* (.070)	0.080 (.083)	.092 (.090)	.066 (.074)
Purchases water	.301** (.136)	0.265** (.132)	0.401*** (.151)	.359** (.158)	.327** (.129)
Surface water & purchase system	–.260* (.154)	–0.299** (.151)	–0.548*** (.180)	–.486*** (.183)	–.442*** (.153)
Population density (100 persons/sq mi)	.006 (.005)	0.000 (.006)	0.014* (.007)	.006 (.007)	.007 (.006)
Treats wastewater	–.096 (.076)	–0.112 (.075)	–0.121 (.081)	–.119 (.082)	–.099 (.074)
Demand factors					
Mean 30-year temperature (°F)		0.024*** (.009)	0.016 (.010)	.035* (.020)	.018** (.009)
Mean 30-year precipitation (in/yr)		0.005 (.005)			
Median household income ($1,000)		0.011** (.005)	0.009* (.005)	.007 (.005)	.006 (.004)
Percent poverty		1.285** (.617)	1.171 (.725)	.782 (.799)	.986 (.644)
Percent elderly		–0.044 (.647)			
Percent owner occupied		–0.181 (.355)			
Median age of town's homes		–0.004 (.004)			
Institutional factors					
County/District			0.229 (.175)		
Sanitary district			–0.252 (.347)		
Metro. district/Authority			–0.197 (.372)		
Has outside rates			–0.258** (.111)	–.296*** (.095)	–.325*** (.084)
Has nonresidential rates			–0.071 (.063)		
Received high unit cost grant			–0.067 (.069)		
Most important objective—affordability			–0.127* (.082)	–.146* (.083)	–.143* (.074)
Most important objective—conservation			0.049 (.375)		
Operating ratio			0.249* (.134)	.250* (.138)	.268**
River basins (16 dummy variables)					
Rho (spatial lag)					.069* (.036)
Observations	202	202	141	145	144
Adjusted R^2	.043	.119	.206	.170	

Note: MGD = million gallons per day. Standard errors in parentheses.
*$p < .1$. **$p < .05$. ***$p < .01$.

Table 6
Chi-Square Statistics for Tests of Joint Significance of Variables in the Cost, Demand, Institutional, and Geographic Factor Models

	(1) Cost	(2) Cost & Demand	(3) Cost, Demand, & Institution	(4) Cost, Demand, Institution, & River Basins	(5) Cost, Demand, Institution, & Spatial Lag
Full model (all variables)	2.30**	2.95***	2.91***	2.09***	N/A
Cost drivers	2.30**	2.07**	2.41**	1.72	14.09**
Demand factors		3.40***	2.54*	1.80	7.63*
Institutional factors			2.96***	6.01***	25.25***
River basins				0.54	
Spatial lag					1.917*

*$p < .1$. **$p < .05$. ***$p < .01$.

using census place data instead of actual service-area population data. A chi-square test indicates that cost factors as a whole significantly impact customer bills.

Introducing demand proxies into the equation barely changes the strength or significance of the cost factors. The group of demand proxies is jointly significant at a 1% rejection level. Utilities in areas with higher temperatures charge higher bills at the average level of consumption, although the magnitude of the effect is small. The average level of consumption was found to be positively correlated with temperature. Changes in median household income are associated with positive increases in average logged bills, but significance tests cannot be rejected beyond a 5% level. The percent of people impoverished in the community is positively correlated with higher logged bills, but this effect disappears in subsequent models as more explanatory factors are included. Overall, the introduction of demand factors increases the explanatory power of the model as measured by the improved adjusted R^2.

The third model includes cost and significant demand factors and adds institutional considerations. Adding institutional factors slightly raises the adjusted R^2 value. The cost drivers and median household income (to a lesser extent) retain their importance in the expanded model, whereas temperature and percent of impoverished can be rejected as significant effects. Utility ownership, rate-setting practices and priorities, and grants do not emerge as significant factors in the bills which customers pay. Moreover, the institutional factors do not pass a test of joint significance at a 10% rejection level. Operating ratio is positively correlated, however, and the presence of outside rate differentials is very strongly associated with lower logged bills for average customers within service boundaries. While rate-setting practices are jointly not statistically significant in this model, affordability as the single-most important criterion in setting rates (above cost recovery, conservation, and developing business-friendly practices) does become statistically significant in the subsequent, more efficient models. Utilities where managers place the highest priority on affordability report a 14% lower combined water and sewer bills, even after controlling for the relative median income of the community.

Model 4 is an extension of Model 2 by including river basins as a factor. Utilities' use of outside rates, primary concern with affordability, and operating ratios were re-included because they were the only institutional factors that passed a test of significance in Model 3 after testing different combinations of institutional variables (these three factors also produced the highest adjusted R^2 values). The addition of river basins, however, does not help explain any of the variation in logged combined bills because the combined effect of river basin location is not jointly statistically significant. In fact, Model 4 has a lower adjusted R^2 and does not provide any improvement over Model 3.

The spatial diagnostic tests performed on Model 4 (after removing river basins) indicated the possible presence of spatial lag (but not spatial errors). Model 5 controls for the presence of spatial lag. The spatial regression controls for spatial lag between utilities within a 32-mile radius, which is the largest minimum distance between any two utilities in the sample. The coefficient on the spatial lag is positive and significant at the 10% level, indicating that the logged combined bills are somewhat positively correlated between neighboring utilities, even after controlling for cost, demand, and institutional factors. Utility size, debt, surface water/purchased water systems, and temperature remain important as they were in the previous models, and cost drivers as a group are significant. The effects of median household income and percent of impoverished on average logged bills decline and become insignificant when location is controlled for through the spatial lag term. Utilities that use outside rates, or where affordability is the highest priority, charge lower logged bills to their inside customers than other utilities, ceteris paribus, while operating ratios remain positively correlated. Model 5 explains the variation in logged combined bills more completely than previous models.

Table 7 summarizes results for the models specific to attitudes concerning affordability and conservation as well as including indicators for future growth. These models use the spatial lag model to examine the importance of growth and perceptions of affordability on (logged) combined bills. They also test whether utilities whose managers view conservation as significant to their utility place a higher value on water, identified via bills at high residential consumption (15,000 gallons per month) and the price signals that utilities send (measured as the absolute and percent difference in actual bills from average to high levels of consumption).

The results from Model 6 suggest that utilities in areas that expect rapid future growth are no more likely to charge higher average bills than areas with lower growth rates. Likewise, the bills for customers who are served by utilities that place a higher consideration on affordability when setting their rates were slightly lower but not statistically different from the bills of other utilities. This result was observed in Models 7 and 8 using the average and a lower level of consumption (3,000 gallons per month). This result seems to contradict the previous finding that

Table 7
Effects of Future Growth and High Significance of Affordability Concerns on Logged Combined Bills and High Significance of Conservation Policies on Water Bills

	(6) Future Growth (Average Water & Sewer)	(7) Affordability (Average Water & Sewer)	(8) Affordability (3K GPM Water & Sewer)	(9) Conservation (15K GPM Water)	(10) Conservation (Average to 15K GPM Water: Absolute Bill Increase)	(11) Conservation (Average to 15K GPM Water: Percent Bill Increase)
Key variable						
Expected 5-year population growth (%)	–0.054 (.109)					
Affordability is significant		0.003 (.057)	–0.044 (.057)			
Conservation is significant				–0.021 (.069)	0.526 (2.808)	0.049 (0.150)
Controls						
Sales (MGD)	–0.011** (.005)	–0.013* (.007)	–0.016** (.007)	–0.000*** (.000)	–0.003* (0.001)	0.000 (0.000)
Long-term debt (million $)	0.002* (.001)	0.002* (.001)	0.002* (.001)	0.000** (.000)	0.000 (0.000)	0.000 (0.000)
Surface water source	0.079 (.076)	0.076 (.077)	–0.008 (.077)	0.184** (.076)	3.972 (3.074)	–0.146 (0.164)
Purchases water	0.348*** (.131)	0.336** (.133)	0.558*** (.133)	0.302** (.130)	7.969 (5.275)	0.239 (0.282)
Surface water & purchase system	–0.447*** (.157)	–0.428*** (.157)	–0.580*** (.156)	–0.305** (.154)	–4.257 (6.248)	0.05 (0.334)
Population density (100 persons/sq mi)	0.007 (.006)	0.008 (.006)	0.002 (.006)	–0.001 (.006)	–0.124 (0.238)	–0.008 (0.013)
Treats wastewater	–0.104 (.075)	–0.094 (.076)	–0.104 (.075)			
Utility also serves sewer				–0.124 (.091)	–7.736** (3.691)	–0.025 (0.197)
Mean 30-year temperature (°F)	0.016* (.009)	0.020** (.009)	0.008 (.009)	–0.002 (.009)	–0.26 (0.384)	–0.040* (0.021)
Median household income (US$1,000)	0.007 (.004)	0.005 (.005)	0.003 (.004)	0.005 (.004)	0.024 (0.175)	–0.005 (0.009)
Percent poverty	1.145* (.657)	0.963 (.656)	0.173 (.655)	–0.033 (.632)	–26.307 (25.707)	–2.629* (1.375)
Has outside rates	–0.348*** (.087)	–0.336*** (.086)	–0.260*** (.086)	–0.216*** (.080)	–3.028 (3.238)	0.111 (0.173)
Most important objective—affordability	–0.144* (.076)			–0.09 (.071)	–2.06 (2.904)	0.067 (0.155)
Operating ratio	0.285** (.123)	0.284** (.125)	0.266** (.125)	0.025 (.109)	–2.016 (4.413)	–0.213 (0.236)
Rho (spatial lag)	0.077** (.036)	0.066* (.037)	0.024 (.041)	0.060** (.029)	0.211** (0.100)	–0.048 (0.119)
Constant	2.234*** (.597)	2.073*** (.600)	2.811*** (.601)	3.864*** (.610)	55.870** (24.742)	4.840*** (1.344)
Observations	140	143	143	184	184	184
Log likelihood	–34.7158	–37.5256	–37.1936	–70.6786	–753.2138	–213.7090

NOTES: MGD = million gallons per day. The dependent variable in Models 6 to 8 is logged combined water and sewer bill, in Model 9 is logged water bill, and in Models 10 and 11 is the increase in the actual water bill in absolute and relative terms, respectively. Standard errors are in parentheses.
*$p < .1$. **$p < .05$. ***$p < .01$.

the utilities for which the highest priority is affordability are more likely to charge lower combined bills at the average consumption level. Table 3 reveals that although 60% of the utility managers mentioned affordability as a significant factor in setting rates, only 20% ranked affordability as the *highest* priority, ahead of cost recovery and other policies. Models 7 and 8 measure the effect of considering affordability as one of several significant factors in rate setting and finds no significant difference in the logged combined bills between the 60% of utilities that consider affordability important and the remaining 40%.

Utilities that value conservation should have higher water bills for residences who consume more water. However, it appears from Model 9 that conservation-minded utilities actually charge their high-yield customers lower water bills (although the difference is not statistically significant) after controlling for other rate factors. The pricing signal that utilities send to their customers (the change in the actual bill as a result of moving from average consumption to 15,000 gallons/month) is higher among conservation-oriented utilities, but the difference is not statistically significant. Moreover, there is no statistical relationship between conservation and price signals as a percentage change in the water bill.

Utility size, debt, surface water/purchased water usage, whether the utility charges different outside water rates, and spatial autocorrelation are all drivers that impact water bills at high units of consumption, as shown in Model 9. The effects of cost, demand, and institution factors change when considering pricing signals. Only utility size accounts for absolute water bill differences, but utilities that provide sewer service also charge a lower bill premium to high-end customers in absolute bill terms. None of the cost factors are significantly associated with percent increases in water bills, yet temperature and percent impoverished are both negatively correlated. Spatial autocorrelation is significant in the absolute bill-change model, but not the percent-change model.

Discussion

This article investigates what factors indirectly affect the bills North Carolina residents are charged for average units of consumption and the pricing signals that utilities send to their customers when they consume more water each month. Results demonstrate that cost factors, such as utility scale, production characteristics, and financial capacity, impact the combined bills that average customers pay for water and sewer service. These come as no surprise, given the propensity of public water and sewer providers to charge rates at a level that attempts to meet cost-of-service requirements.

Some demand-side factors influence how much consumers pay for service, such as temperature, median household income, and poverty rates in the community. Customers living in areas with higher temperatures may be consuming more water on average, thereby increasing the combined bills they receive for their average level of consumption. This association was tested and found to be positive in our sample. Utilities with higher median household incomes charge more for services when cost, institutional, and other demand factors are taken into account. Surprisingly, percent poverty is positively correlated with higher combined bills in Model 2. Because median community wealth is already controlled for in the model via median household income, the effect of percent poverty takes into account the distribution of income at the lower end of the community. The coefficient on percent poverty in Model 2, therefore, implies that higher levels of income disparity in the community are associated with higher combined bills. Such practices indicate a potentially significant “affordability gap” for lower-income households in communities with overall higher levels of income. The inclusion of institutional and location variables (river basins or spatial lag), does, however, dampen the effect of community income and disparity on combined bills at the average consumption level.

Varying forms of public ownership did not impact combined bills. This bolsters findings from previous studies on ownership that suggest little difference in ownership’s effect on cost structure. Utilities that differentiate between residential and nonresidential customers do not charge residential bills that are significantly different from those who do not make this distinction. However, there is evidence that utilities are providing cross-subsidies to customers within their regular service boundary at the expense of their “outside” customers. More information on the extent to which utilities are recovering the costs of capital extensions for outside customers and nonoperating revenue flows is necessary to further determine how these cross-subsidies are taking shape.

Respondents consider cost recovery as the most important rate-setting objective in a majority of cases, yet a significant minority of utilities has failed to recover operating costs. As expected, utilities that are more successful at recovering operating costs charge higher combined bills. Those utilities that are not meeting their operating costs should consider rate increases to deal with their shortfalls. It also appears that utilities that place a higher priority on affordability than cost recovery or other policies tend to charge lower bills for average consumption than other utilities, controlling for all other factors. This effect is only evident when affordability surpasses cost recovery and other policies as the primary rate-setting priority, not when affordability is considered as one of several "significant" factors in rate setting. The survey and regression results reflect the difficult tradeoff that some managers face between meeting their operating costs and keeping rates affordable through rate-setting practices.

The study also provides empirical evidence that utilities are "looking over their shoulder" when setting rates. Spatial lag successfully predicts bills at average, low-end, and high-end consumption patterns as well as pricing signals. The presence of spatial autocorrelation within a 60-mile radius and the significance of neighboring utilities' bills on one's own bill imply at the least that the values of utility bills are closer to one another than they are across other areas of the state. Political competition to set rates at least not higher than the rates set by utilities in neighboring jurisdictions may be encouraging utility managers to look at nearby utilities when setting prices. Rates surveys are abundant and very popular among utilities, with even local media outlets reporting on portions of such surveys. Personal correspondence with individuals responsible for setting utility rates confirmed these external pressures on local officials to set regionally comparable rates. Additional investigations would better determine the causal nature of these relationships; yet at a minimum, the results reflect some concern that utility managers and decision makers may be more concerned about regional "benchmarking" than about setting appropriate rates for their communities' needs.

Utilities that claim conservation is a significant priority in their water rate–setting practices are no more likely to charge higher bills (Model 9) or higher marginal prices for high-volume customers than other utilities. Nor are conservation-minded utilities any more likely to send a stronger pricing signal to those consumers who look at the absolute or relative bill difference as their gauge for determining how much they will consume. Given the extreme drought conditions affecting most parts of North Carolina today, these findings suggest that utilities have much more work to do in promoting conservation as a rate-setting objective. Unlike cost recovery and affordability objectives, for many utilities conservation has not reached the point where a significant group of decision makers are practicing what they claim to preach.

More research is needed to examine what factors theoretically and empirically predict determinants of price signals (changes in price on the basis of changes in consumption). Results here suggest that traditional cost factors do not explain these signals adequately, whereas alternative specifications of the dependent variable (absolute vs. relative difference) indicate that other factors are not very robust. In addition, this study was unable to collect information on how consumers actually respond to price changes in practice. A more experimental inquiry among a set of utilities with different characteristics would make a further contribution in this interesting avenue of new research.

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