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Abstract

Recent empirical research for municipal water consumption has uncovered a variety of interesting growth patterns. This study examines municipal water usage over time for Halifax, Nova Scotia, the thirteenth largest metropolitan economy in the Canada. Results from a dynamic error correction modeling approach estimated using quarterly frequency data indicate that municipal water consumption reacts in statistically significant manners to changes in real price, per capita employment levels, and hot weather. Parameter estimates further indicate that any disequilibria in consumption tend to dissipate very quickly in Halifax. As in other regions, the number of utility customers is affected by demographic and labor market variables.

Résumé

Recherches empiriques récentes ont trouvé une variété de tendances qui existent dans la consommation d'eau au niveau municipal. Cette étude analyse la consommation d'eau au fil du temps, à Halifax, en Nouvelle-Écosse, le treizième plus grande économie métropolitaine au Canada. Les résultats d'une modèle dynamique de correction d'erreurs, estimée avec des données trimestrielles indiquent que la consommation d'eau réagit de manières statistiquement significatives aux variations des prix réels, l'emploi, et le climat. Les paramètres estimés indiquent que tout déséquilibre de la consommation à Halifax est éliminé assez rapidement. Tout comme dans d'autres régions, le nombre de consommateurs d'eau est affecté par la démographie et par le marché du travail.

Keywords

Municipal Water Consumption, Halifax Metropolitan Economy, Applied Econometrics

JEL Category

Q25, Water Demand; R15, Regional Econometrics; M21, Business Economics

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Introduction

Municipal water systems are costly to develop, maintain, and manage. Planning efforts require at least some understanding of customer level and consumption volume behaviours. Econometric analysis offers one tool that can be useful in this regard.

Halifax, Nova Scotia is located on the east coast of Canada in the Atlantic region, an area known for its cool climate and heavy precipitation. Halifax Regional Municipality supplies approximately 400,000 people with clean, fresh, potable water, using a 1,300 kilometer network of pipes and other infrastructure (HRM, 2007). Although Halifax is fairly large and growing, econometric analysis of its municipal water consumption patterns has not previously been attempted.

The objective of this study is to analyze quarterly water consumption in Halifax. An analysis of water consumption patterns may provide insight regarding the future of this public service in this metropolitan economy. In-sample estimation diagnostics and out-of-sample model simulations are employed to verify overall model reliability.

In subsequent sections, a brief overview of prior studies related to water consumption follows. Data and methodology are described next. Empirical results are then summarized. Policy implications are also outlined and discussed. The final section includes a summary and suggestions for future research.

Literature Review

Long-term forecasts are helpful for planning, designing, and building future extensions of water systems, while short-term forecasts are used in the operation and management of existing water systems (Jain *et al.*, 2001). Development of monthly short-term models is usually feasible because they typically do not require very extensive data sets (Hansen and Narayanan, 1981; Sankaran and Viraraghavan, 1992). Long-term, system of equation model development is often hindered by more voluminous data requirements. Although long-term forecasting analysis is difficult to carry out, the impacts of infrastructure capacity and financial constraints on urban water system development in Canada are fairly well known (McFarlane and Nilson, 2003).

Concerns over rapid economic growth and supply concerns have led to a number of recent econometric studies of municipal water usage in arid regions (Fullerton and Nava, 2003; Fullerton and Elias, 2004; Fullerton *et al.*, 2006; Fullerton *et al.*, 2007). Variables employed include per meter water consumption levels, rainfall, ambient temperature, average price, with employment and/or industrial production measures utilized as business cycle indicators. Customer bases in these models are generally modeled as functions of demographic and labor market variables.

Not all water consumption patterns studies have been completed for arid climate regions. Hamlet and Lettenmaier (2000) use stream flow techniques to analyze the long range climate forecasting and its use for water management in the Pacific Northwest region of North America. Also, Schleich and Hillenbrand (2009) examine the determinants of per capita residential water demand in Germany using a double-log model and two semi-log models. Harris (1992) reports elasticities of demand for water in 57 communities in Quebec that are well within the ranges reported for cities in other countries. Also using cross sectional data, Olmstead *et al.* (2003) obtain similar results for the Waterloo-Cambridge metropolitan economy in Ontario.

Pricing issues have been extensively examined in recent studies of municipal water demand in Canada (Environment Canada, 2008). One study with important implications for this one is Reynaud *et al.* (2005). Results in that effort indicate rate structure endogeneity exists at many Canadian water utilities. Failure to take into account simultaneity between prices and consumption can lead to biased parameter estimates. Many water consumption studies employ average rates as price measures due to data constraints (Dalhuisen *et al.*, 2003; Fullerton and Elias, 2004). Because that places consumption on both sides of the specification, endogeneity tests should be deployed in such situations.

Numerous economic, social, and environmental factors affect the demand for residential fresh water and are expected to undergo substantial change in the near future. More specifically, water prices may rise in response to increased scarcity, grid maintenance, and/or reconstruction requirements. Sewage prices may increase because of environmental investments to control harmful substances. Prices may change if cross-border and/or regional water markets are deregulated. Because water infrastructure systems are large technical systems with useful lives often lasting more then 50 years, the costs for adapting systems can be high when water demand does not evolve as predicted (McFarlane and Nilson, 2003; Schleich and Hillenbrand, 2009).

The analysis completed is similar to some that have been conducted for other metropolitan economies (Hoffman *et al.*, 2005; Schleich and Hillenbrand, 2009). Variables used in this study include the number of customers, water consumption levels in cubic metres, population, average price per cubic meter, and ambient weather indicators. To examine both short-run and long-run water consumption patterns in Halifax, an error-correction modeling approach is utilized. As noted by Bell and Griffin (2011), there are still relatively few studies that take water consumption dynamics into account. The one implemented below does not have extensive data requirements associated with it.

Data and Methodology

A fairly good variety of data are available for investigating water consumption dynamics in Halifax. They include revenues, total municipal water consumed in cubic metres, wastewater costs, environmental protection costs, weather patterns, and total employment. For this study, those data are collected at a quarterly frequency from the second quarter of 1996 through the first quarter of 2009. Aggregate water consumption in cubic metres, wastewater costs, environmental protection costs and revenue data are reported by Halifax Regional Water Commission. Weather indicators such as ambient temperature, rainfall, and snow fall data for Halifax are recorded by Environment Canada. Employment and price index data are collected by Statistics Canada. For local business cycle measurement, the employment series provides the broadest gauge currently available for Halifax at a quarterly frequency.

Historical data for consumption, meter charges, and tariffs in Halifax are not presently available. Monthly base fees vary by meter size across customer categories, but the water and wastewater prices per cubic meter are flat rates. Quarterly cubic metres consumed and the number of active accounts do allow a per customer consumption series to be calculated across all rate categories. Only metered water is included. Because leakages do not reach customers, they are excluded from the average rate calculation. Independent variables include average price, non-seasonally adjusted employment, number of customers, and weather series. The latter include average temperature, snow, and rainfall, total precipitation, cooling degree days, and heating degree days.

As in Arbues *et al.* (2004), an average price measure is employed in the empirical analysis. To approximate a quarterly price series, total revenue, inclusive of meter fees and usage charges, is divided by total water and wastewater consumed. Environmental protection charges per cubic meter consumed for each quarter is then added to the average revenue estimate. The resulting average price per cubic meter series is deflated using quarterly values of the consumer price index. The same approach is frequently employed when detailed public utility tariff information is not available or difficult to obtain (Shin, 1985). It has also been shown to yield reliable econometric results (Nieswiadomy and Molina, 1991; Dalhuisen *et al.*, 2003). However, because of the manner in which the price measure is calculated, it will be important to test for endogeneity.

During much of the year Halifax has a cool, wet climate, but it does experience warmer summer temperatures. Dating back to 1996, Halifax has observed average temperatures above 18.3 degrees Celsius during the months of May through September. Both heating and cooling degree days are calculated with a generally accepted base temperature and are reflective of the personal preferences of people who live or work in buildings (Stathopoulou *et al.*, 2006). For the purpose of this study, temperatures below 18.3 degrees Celsius yield heating degree days, while those above 18.3 degrees Celsius generate cooling degree days. As in other studies, periods with higher temperatures are expected to observe greater water usage than periods with lower temperatures (Fullerton *et al.*, 2007; Monteiro and Roseta-Palma, 2011).

Population, as provided by the Halifax Greater Chambers of Commerce, is recorded annually. The number of customers provided by Halifax Water Commission is also recorded annually. In order to obtain quarterly frequency estimates for both series, interpolations are carried out using employment data patterns to generate quarterly estimates of population and customers (Friedman, 1962; Fernandez, 1981). That may introduce endogeneity for Equation 3 and testing will have to be utilized to determine whether instrumentation is required to address it. Because quarterly personal income data are not available for Halifax, the employment to population ratio is used as a regressor below. Employment variables have been successfully utilized in other regional water consumption studies when income estimates are not available (Fullerton and Elias, 2004; Musolesi and Nosvelli, 2011).

Descriptive statistics for the variables utilized are shown in Table 1 and graphs of those series are displayed in Figure 1. The maximum level of water demand observed over the course of the sample period is 11.7 million cubic metres. That aggregate level of consumption was registered during the fourth quarter of 2002. Subsequent to that date, water consumption follows a gently downward-sloping trend. In contrast, local employment, population, and the water customer base increase steadily over the course of the sample period. Not surprisingly, the real price of water also rises considerably during the period under consideration.

Table 1. Summary statistics

Figure 1. Graphs

The general model for water demand posits consumption as a function of price, employment, and weather conditions. A standard long-run consumption per customer specification, with logarithmically transformed data, is shown in Equation 1. In Equation 1, C is total municipal water consumed or sold, CSM is the number of utility customers, P is the quarterly average real price per cubic meter, E is employment, POP is population, CLIM is a climate measure such as rainfall or cooling degree days, u is a stochastic disturbance term, and t is a time period index.

$$\mathrm{Ln}(C_t/CSM_t) = a_0 + \underset{(-)}{a_1\mathrm{Ln}(P_t)} + \underset{(+)}{a_2\mathrm{Ln}(E_t/POP_t)} + \underset{(-\text{ or }+)}{a_3\mathrm{Ln}(CLIM_t)} + u_t \qquad (1)$$

In Equation 1, a_0 is the intercept term. The hypothesized sign for each slope parameter is shown in the parentheses below the expression. An inverse relationship is anticipated with respect to real price. Improvements in the local economy, approximated by employment per capita, should lead to increases in the consumption of water. In the case of the climate variables, the expected sign will vary. Increased rainfall will tend to reduce water usage, while higher temperatures will generally increase usage (Hansen and Narayanan, 1981; Fullerton and Elias, 2004).

Beyond the long-run relationships shown in Equation 1, it may be helpful to also examine short-run characteristics of Halifax water consumption:

$$d(\mathrm{Ln}(C_t/CSM_t)) = b_0 + \underset{(-)}{b_1 d(\mathrm{Ln}(P_t))} + \underset{(+)}{b_2 d(\mathrm{Ln}(E_t/POP_t))} + \underset{(-\text{ or }+)}{b_3 d(\mathrm{Ln}(CLIM_t))} + \underset{(-)}{b_4 u_{t-1}} + v_t \qquad (2)$$

In Equation 2, d is the difference operator, b_0 is the intercept term, and v_t is a random disturbance term. The hypothesized sign for each slope coefficient is shown in the parentheses below the expression. Because consumers will adjust to any prior period disequilibria, the expected sign for the error correction term, u_{t-1}, is negative. Inclusion of this equation is designed to potentially help clarify short-run consumption dynamics for the municipal water system in Halifax.

Consumption is recorded as total cubic metres of water consumed per quarter. Water consumption in Halifax declined from 2002 through 2009 by an average of one percent per year.

Several factors contribute to this development. Public awareness campaigns similar to those employed in other regions have been utilized since the 1990s to promote greater conservation (van Niekerk *et al.*, 1995; Worthington and Hoffman, 2008). Specific efforts have encouraged the adoption of more water efficient appliances such as low flow shower heads, aerator faucets, low flow toilets, and front loading washing machines. Finally, Halifax Water Commission also sends warnings to customers who are deemed to consume excessive amounts of water. The excess usage threshold is based on an undisclosed benchmark. The letters are designed to make high volume users aware of their consumption patterns. The specification shown in Equation 2 does not attempt to account for those programs because the sample does not extend far enough into the past to allow introducing qualitative variables needed to represent them (Fullerton and Schauer, 2001).

Anticipating changes in the numbers of customers is an important planning step for water utilities, as new metres, distribution pipes, water mains, and other infrastructure must be installed for the new addresses. Accordingly, an equation is also specified for the number of customers. To account for both demographic and economic expansion impacts on the water grid, population and employment are used as explanatory variables in Equation 3. In Equation 3, c_0 is the constant and w_t is a stochastic error term.

$$Ln(CSM_t) = c_0 + \underset{(+)}{c_1 Ln(POP_t)} + \underset{(+)}{c_2 Ln(E_t)} + w_t \qquad (3)$$

Data requirements for the equations outlined above are not very extensive. For many utilities, this is an important consideration due to internal information and records limitations (Billings and Jones, 1996). For some utilities, model design parsimony may be driven by ineffective estimation and/or simulation results associated with more complicated specifications than the one shown above. For many others, if not most, a parsimonious approach will be useful since it will avoid going beyond the limits of available data.

Empirical Analysis

Initial parameter estimation exercises employed several combinations of the variables collected for this study. Results from those steps are generally in line with what has been reported for other water utilities, but climate does not appear to influence municipal water consumption as much in Halifax as in other metropolitan economies where multiple weather regressors are required to adequately model consumption (Pint, 1999; Mieno and Braden, 2011). As shown in Table 2, the parsimonious specification selected for consumption per customer includes real price (fitted), employment per capita, and cooling degree days as the regressors.

Because consumption appears in the numerator of the dependent variable and in the denominator of the average price explanatory variable, simultaneity is an obvious risk of the manner in which the model is specified. Given that, an artificial regression test for endogeneity is carried out (Davidson and MacKinnon, 1989). The artificial regression test uses a two-stage (2SLS) instrumental variables procedure in which the average price is modeled as a function of exogenous variables from the original specification plus instrumental variables that are potentially correlated with water price variations in Halifax. The residuals from this equation are then included as a regressor in the original specification. If the coefficient for that regressor is not significant, simultaneity is not a problem and ordinary least squares (OLS) can be utilized to estimate the parameters in Equation 1. If the residual explanatory variable parameter is significant, then the fitted price variable from the first equation should be used as the regressor in the consumption per customer equations.

Three variables from Statistics Canada are used as instruments for that test. They include the real Canadian water utility index for capital and repair expenditures, the real Canadian machinery and equipment price index for utilities, and the ratio of non-federal gross debt to Canadian gross domestic product. The computed t-statistic for the residuals in the second equation of the artificial regression test, 3.142, is significant at the 1-percent level. That result rejects the consistency of OLS parameter estimates for the long-run cointegrating equation. Accordingly, the fitted estimate of the average price variable obtained with the instruments is used for the 2SLS estimated version of Equation 1 shown below. The artificial regression test for endogeneity may prove attractive to other water utilities because of its relative ease of implementation.

Table 2. Long-run cointegrating equations

For comparative purposes, Table 2 reports estimation results using both 2SLS instrumental variables and OLS. No matter which method is employed, the estimated parameters for each of the variables have the expected signs and either exceed or come close to satisfying the 5-percent significance criterion. The coefficient magnitudes for the constant term and for cooling degree days are roughly the same regardless of which estimation procedure is used. The same does not hold true for the parameter estimates for price and per capita employment.

In the case of the coefficient for the average real price variable, the 2SLS estimate exceeds, in absolute terms, the OLS estimate by 36 percent. The 2SLS estimate thus indicates that Haligonian municipal water usage is substantially more responsive to price changes than what the OLS coefficient implies. The difference between the 2SLS and the OLS per capita employment elasticities is even larger, 128 percent. Again, this indicates that failure to take into account price and consumption simultaneity via 2SLS can result in parameter estimates that substantially underestimate the responsiveness of water consumption to variations in key explanatory variables. From a planning perspective, it also indicates that water authorities can attain desired objectives with respect to revenues and per customer usage with smaller rate increases than what the OLS results indicate.

The magnitude of the price coefficient easily falls within the range of long-run elasticities previously reported for other water utilities and regions (Espey *et al.*, 1997). Water demand inelasticity means that the consumption patterns of Halifax Water Commission customers are fairly well ingrained and usage levels are not overly sensitive to small price changes. Interaction terms are tested to determine whether changes in employment, population, or climate variables condition the impact of price on water demand, but the parameter estimates are not statistically significant at conventional levels.

The employment per capita variable is used as an indicator of overall economic conditions. Its magnitude is similar to those obtained in other water demand studies that rely upon labor market variables as explanatory variables in lieu of personal income estimates (Hussain *et al.*, 2002; Fullerton and Elias, 2004). This coefficient indicates that increases in employment per capita are associated with proportionately larger increases in per customer consumption. The latter potentially reflect increased rates of household formation as a consequence of stronger economic performance. A similar result with respect to single-family housing is also found in Schleich and Hillenbrand (2009).

The only weather regressor included in the consumption per customer equations is cooling degree days. As hypothesized, warmer temperatures lead to greater water usage, but not by very much. The size of the cooling degree days elasticity shown in Table 2 is substantially smaller that what has been documented for other utilities and regions (Fullerton and Nava, 2003; McFarlane and Nilson, 2003; Mieno and Braden, 2011). The latter may reflect the fact that summer days are rarely that uncomfortable in this metropolitan economy. Although the coefficient for this regressor does not satisfy the 5-percent criterion, it does meet the 10-percent guideline that is often utilized in regional econometric work (for example, Rork and Wagner, 2008).

A unit root test performed on the 2SLS long run equation residuals rejects the unit root presence hypothesis at a 5-percent confidence level (Elliott *et al.*, 1996). That outcome indicates that a cointegrating relationship has been found and the long run equation should be statistically reliable. Because quarterly frequency data are utilized in the analysis, it is also important to test for the presence of seasonal unit roots. The test employed is that proposed by Hylleberg *et al.* (1990). Empirical results from this test applied to the 2SLS long run equation residuals also reject the seasonal unit root hypothesis. The computed test statistic is 9.33, while the 5-percent critical value for the null hypothesis is 6.55. Again, that implies that the residuals are stationary and the estimated equation should be statistically reliable. A graph of the residual series is shown in Figure 2.

Figure 2. Residuals of the long-run cointegrating equation

The short-run error correction estimation results are shown in Table 3. It shows the effects real price, employment, cooling degree days and rainfall have on the dependent variable consumption of water in the short-run. The price coefficient in Table 3 is significant at the 5-percent level and carries a negative sign as hypothesized. The short-run price elasticity in Halifax is inelastic at -0.31, falling squarely within the range of values reported by Espey *et al.* (1997) and very close to that calculated for municipalities in Quebec by Harris (1992). As with long-run cointegrating equation, the seasonal unit root hypothesis is rejected at the 5-percent level. The computed test statistic of 10.55 easily exceeds the 6.55 critical value (Hylleberg *et al.*, 1990).

Table 3. Short-run error correction equation

The employment parameter is positive, as expected and also satisfies the 5-percent criterion. The magnitude of that coefficient indicates that municipal water consumption is very sensitive to changes in metropolitan economic conditions in Halifax. It is higher than the estimates reported in studies of other regional economies (Fullerton *et al.*, 2006). The cooling degree days coefficient in Table 3 is not statistically distinguishable from zero. While surprising for a short-run equation, that result is similar to what Schleich and Hillenbrand (2009) report for municipal water consumption in Germany.

The error correction term shows how water usage in Halifax adjusts to any consumption disequilibria from the prior period. Consumption disequilibria may occur in part because water consumption patterns tend to change slowly due to durable appliance stocks and persistent customer habits (Musolesi and Nosvelli, 2011). The estimated parameter for the error correction term, U-Resid(-1), is significant at the 5-percent level and negative, as hypothesized. Its magnitude indicates that a large percentage of any prior period deviation from equilibrium is quickly reversed. The coefficient estimate implies that it takes approximately 1.3 quarters (or 17 weeks) for consumption per customer disequilibria to completely dissipate.

Table 4 measures the effects of population and employment upon the number of customers. All of the estimated coefficients satisfy the 5-percent significance criterion. The water grid reacts elastically with respect to increases in the population of Halifax. That probably implies that population gains spur both residential and commercial development plus associated growth in the number of accounts and hook-ups to the water system. The number of customers is less sensitive to increases in employment, but still responds in a direct manner to changes in that variable. Inclusion of a one period lag of the prediction error, MA(1), is necessary to correct for autocorrelation (Pagan, 1974). Because parameter estimation requires residuals from the periods prior to each observation beginning in the second quarter of 1996, the error for the first quarter of 1996 is estimated by backcasting (Box *et al.*, 2008). A unit root test performed on the residuals rejects the null hypothesis at the 1-percent confidence level, implying that a cointegrating relationship has been found. A similar outcome is documented for the seasonal unit root test also conducted for this equation.

Table 4. Halifax municipal water customers equation

Policy Implications

Halifax Regional Municipality has put into place a rebate program for energy for residential users who purchase electricity for their homes (HRM, 2007). A similar program could be put into place by the Halifax Regional Water Commission to provide incentives for its customers to make their homes more water efficient (Grafton *et al.*, 2011). Many of the homes in Halifax are old with aged pipe structures and inefficient appliances, such as dishwashers, toilets, and hot water heaters. A rebate program would reduce the costs of switching to water saving appliances and upgrading the pipe structures. Doing so would entail fairly substantial budgetary outlays, but these could be covered via higher rates or temporary surcharges in place over the life of the rebate program. Haligonian water demand is inelastic with respect to price, so tariff increases provide one means for generating additional revenues in support of capital upgrades and grid maintenance by the utility.

The water commission uses a pay as you use meter system that shows consumers exactly how much water is being utilized and the expenditure associated with it. This policy will help consumers budget their water usage when considering all bills (Millock and Nauges, 2010). As prices rise, consumers can observe the impacts of the increases on their bill in real-time equivalents. That implies that the lagged reaction times observed as a consequence of billing cycles at many utilities will continue to not be observed in Halifax (Fullerton and Nava, 2003; Fullerton *et al.*, 2007). It also means that customer usage efficiencies will be realized more quickly. However, because water demand is inelastic, public awareness campaigns will probably also need to be maintained in future years in order to enhance conservation gains (White and Fane, 2002; Grafton *et al.*, 2011).

According to Environment Canada (2009), approximately five percent of all Canadian municipalities have adopted specific water conservation targets. Elasticity estimates, such as those in tables 2 and 3, can be used to simulate the rates of change in prices that will be necessary to achieve specific demand targets. For example, if the Halifax Water Commission should establish a policy to prevent further growth in water consumption, it would need to consistently increase real water prices at a rate of 3.1 percent per year, assuming that other independent variables continue to follow their historical growth trends. That rate of growth in prices is within the range of tariff increases actually observed in Halifax over the course of the sample period.

Halifax is one of the Canadian metropolitan economies whose population base grows at a fairly steady rate. That demographic expansion increases the customer base served by Halifax Water. Increases in the number of customers require fairly pronounced capital outlays to extend the water and sewer grid infrastructure and also lead to greater volumes of water dispersion from the utility reservoirs. Higher prices, while politically unpopular, will help generate the revenues necessary to cover the ongoing expansion of the grid. They can also help encourage more usage efficiencies and relieve potential capacity constraints that would otherwise be faced at the reservoirs.

On average, Halifax residential customers consume 55 cubic metres per quarter. If the real price of water increases by 10 cents over the highest real price in the original data set, CA$1.67, there will be a CA$2.82 increase in revenue per quarter per customer. That represents an approximate CA$224 thousand in aggregate revenues each trimester. This example uses only the average residential consumption patterns for the new customers because the averages for the amount of water consumed per quarter of other customers such as industrial or commercial users are currently not available. Because commercial and industrial usage is higher, the total revenue gain would actually be greater if non-residential tariffs are also raised. Those potential revenues could help pay for any new infrastructure development and/or upgrades.

In addition to population growth, the results shown in Table 4 further indicate that economic growth creates additional pressure to expand the municipal grid. As in other areas of Canada, and elsewhere, periods when rapid employment growth causes regional payrolls to swell will likely be associated with faster housing construction and non-residential property development (Bougadis *et al.*, 2005; Yoo, 2007). Such periods will require substantial infrastructure investment that will generally require, due to metropolitan business cycle effects that drive up regional prices and wages, unusually expensive materials and labor inputs. To deal with the abnormally high costs of construction during such periods, Halifax Water may also consider implementing impact fees. While generally unpopular among construction developers, there is a long history of such assessments with many fee schedule designs available to water system authorities (Clark, 1994). Because water tariffs have increased substantially in recent years in Halifax, impact fees might offer an additional source of funding that may prove useful.

Conclusion

In this study, an error correction model is estimated to help analyze municipal water consumption patterns in Halifax, Nova Scotia, Canada. The data employed are quarterly frequency time series of water consumption per customer, average real price, employment per capita (in lieu of personal income), and cooling degree days. To date, relatively few econometric studies of municipal water consumption patterns have been completed for Halifax or other temperate zone, water abundant regions using error correction models. An attractive feature of the approach selected is that it allows for both short-run and log-run dynamics to be taken into account.

Another attribute of the model employed in this study is that the data requirements are not very extensive, an important consideration for many water utilities in Canada and elsewhere. When detailed price data are not available, as is often the case, average revenue per unit of water consumed may be used instead. However, this analysis points out that price variables calculated as the ratio of revenue to consumption may introduce endogeneity into the regression equation. If endogeneity is present, OLS will potentially yield inconsistent parameter estimates. In this study, estimation is carried out using two-stage least squares, a viable alternative estimation procedure for cases in which endogeneity is found to exist in the water demand equation. The 2SLS results indicate that taking into account simultaneity between consumption and average price also results in larger coefficients for the price and employment coefficients in the per customer consumption equation.

Quarterly water consumption is found to react fairly quickly to changes in both economic and climatic variables in Halifax. Overall estimation results are fairly strong. Not all of the estimated coefficients satisfy the 5-percent significance criterion, but the parameter magnitudes obtained are well within the ranges reported in previous empirical work. Regression results for the number of municipal water customers points to strong influences from both demographic and labor market conditions. Perhaps due to the inclusion of a climate variable in the consumption equations, seasonal non-stationarity is not found to be a problem.

Halifax municipal consumption reacts in a statistically significant manner to variations in the real price charged for water. Similar to what is observed for other public utilities, consumption is price inelastic in this metropolitan economy. Most price increases will not lead to notable usage reductions. Additional revenues generated from higher rates can, however, be employed to finance other means of encouraging greater efficiency. Examples include public awareness campaigns as well as infrastructure upgrades and maintenance.

Because personal income data are not available at a quarterly frequency for Halifax, total employment is utilized as an indicator of overall economic conditions. Increases in employment per capita are shown to increase water consumption in statistically significant and elastic manners. Business cycle upswings that coincide with those rare periods during which precipitation is below average or quasi-drought conditions are observed, may, therefore, lead to water supply constraints. While this combination of events may seem somewhat unlikely, usage restrictions and/or temporary surcharges such as those implemented by utilities located in arid and semi-arid regions may become necessary should those conditions ever be observed in Halifax.

Because the data requirements for the error correction approach employed are not very extensive, it may be possible to replicate this effort for other metropolitan economies to develop a better understanding of municipal water consumption patterns. For some regions, it may be feasible to improve upon what is presented herein by utilizing marginal rate and personal income data. Empirical analyses of different tariff categories such as those for single family, multifamily, commercial, and industrial customers may also be possible for some public utilities. Capital costs and supply constraints make it likely that utility managers will require accurate information regarding system demand behavior and customer base growth to support future infrastructure investment and operations planning efforts.

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Table 1. Summary statistics

	Mean	Standard Deviation	Minimum	Maximum	No.
Consumption[1]	10,491,587	593,688	9,301,224	11,661,285	52
Customers	72,792	3,693	65,960	79,384	52
Real Price[2]	\$1.23	\$0.32	\$0.66	\$1.67	52
Employment	191,762	14,104	164,400	213,900	52
Population	374,877	12,591	353,490	398,049	52
Cooling Degree Days	28	33	0	90	52

1. Cubic metres consumed
2. Real Canadian dollars per cubic meter

Table 2. Long-run cointegrating equations

Dependent Variable: LOG(C / CSM)
Method A: Two Stage Least Squares with Instrumental Variables (2SLS)
Sample: 1996Q2 - 2009Q1
Included observations: 52

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	5.841118	0.290177	20.12947	0.0000
LOG(P-Fitted)	-0.459810	0.067873	-6.774557	0.0000
LOG(E / POP)	1.205643	0.414082	2.911607	0.0054
LOG(CLIM-CDD)	0.007899	0.004071	1.940212	0.0582

R-squared	0.683565	Mean dependent var.	4.970420
Adjusted R-squared	0.663788	Std. dvn. dep. variable	0.089204
S.E. of regression	0.051724	Durbin-Watson statistic	1.908911
Sum squared resid.	0.128417	Second stage SSR	0.108385
F-statistic	37.05918	Prob. (F-statistic)	0.000000
Seasonal unit root F	9.334572	Significance level	0.050000

Dependent Variable: LOG(C / CSM)
Method B: Ordinary Least Squares (OLS)
Sample: 1996Q2 2009Q1
Included observations: 52

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	5.364783	0.216738	24.75236	0.0000
LOG(P)	-0.338242	0.047814	-7.074172	0.0000
LOG(E / POP)	0.529496	0.310225	1.706812	0.0943
LOG(CLIM-CDD)	0.008392	0.003818	2.197990	0.0328

R-squared	0.721123	Mean dependent var.	4.970420
Adjusted R-squared	0.703693	Std. dvn. dep. variable	0.089204
S.E. of regression	0.048557	Durbin-Watson statistic	1.933079
Sum squared resid	0.113175	Log likelihood	85.59683
F-statistic	41.37295	Prob. (F-statistic)	0.000000
Seasonal unit root F	11.30590	Significance level	0.050000

Table 3. Short-run error correction equation

Dependent Variable: D(LOG(C / CSM))
Method: Least Squares
Sample (adjusted): 1996Q3 - 2009Q1
Included observations: 51 after adjustments

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	-0.005932	0.006794	-0.873175	0.3871
D(LOG(P-Fitted))	-0.307930	0.055154	-5.583132	0.0000
D(LOG(E / POP))	2.081462	0.483277	4.306979	0.0001
D(LOG(CLIM-CDD))	-0.002615	0.003265	-0.800915	0.4273
U-Resid(-1)	-0.755348	0.164172	-4.600942	0.0000

R-squared	0.618567	Mean dependent var.	-0.005152
Adjusted R-squared	0.585398	Std. dvn. dep. variable	0.071920
S.E. of regression	0.046309	Schwarz inf. criterion	-3.024678
Sum squared resid.	0.098647	Hannan-Quinn criterion	-3.141700
Log likelihood	86.95886	Durbin-Watson statistic	1.978498
F-statistic	18.64943	Prob. (F-statistic)	0.000000
Seasonal unit root F	10.54786	Significance level	0.050000

Table 4. Halifax municipal water customers equation
Dependent Variable: LOG(CSM)
Method: Least Squares
Sample (adjusted): 1996Q2 - 2009Q1
Included observations: 52
MA Backcast: 1996Q1

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Constant	-5.626068	0.884228	-6.362691	0.0000
LOG(POPULATION)	1.169585	0.112589	10.38811	0.0000
LOG(EMPLOYMENT)	0.148841	0.050596	2.941777	0.0050
MA(1)	0.812438	0.081444	9.975471	0.0000

R-squared	0.991491	Mean dependent var.	11.19410
Adjusted R-squared	0.990959	Std. dvn. dep. variable	0.050950
S.E. of regression	0.004845	Schwarz inf. criterion	-7.597984
Sum squared resid.	0.001127	Hannan-Quinn criterion	-7.690537
Log likelihood	205.4501	Durbin-Watson statistic	1.766018
F-statistic	1864.253	Prob. (F-statistic)	0.000000
Seasonal unit root F	35.28709	Significance level	0.050000

Figure 1: Time series of variables employed for statistical analysis

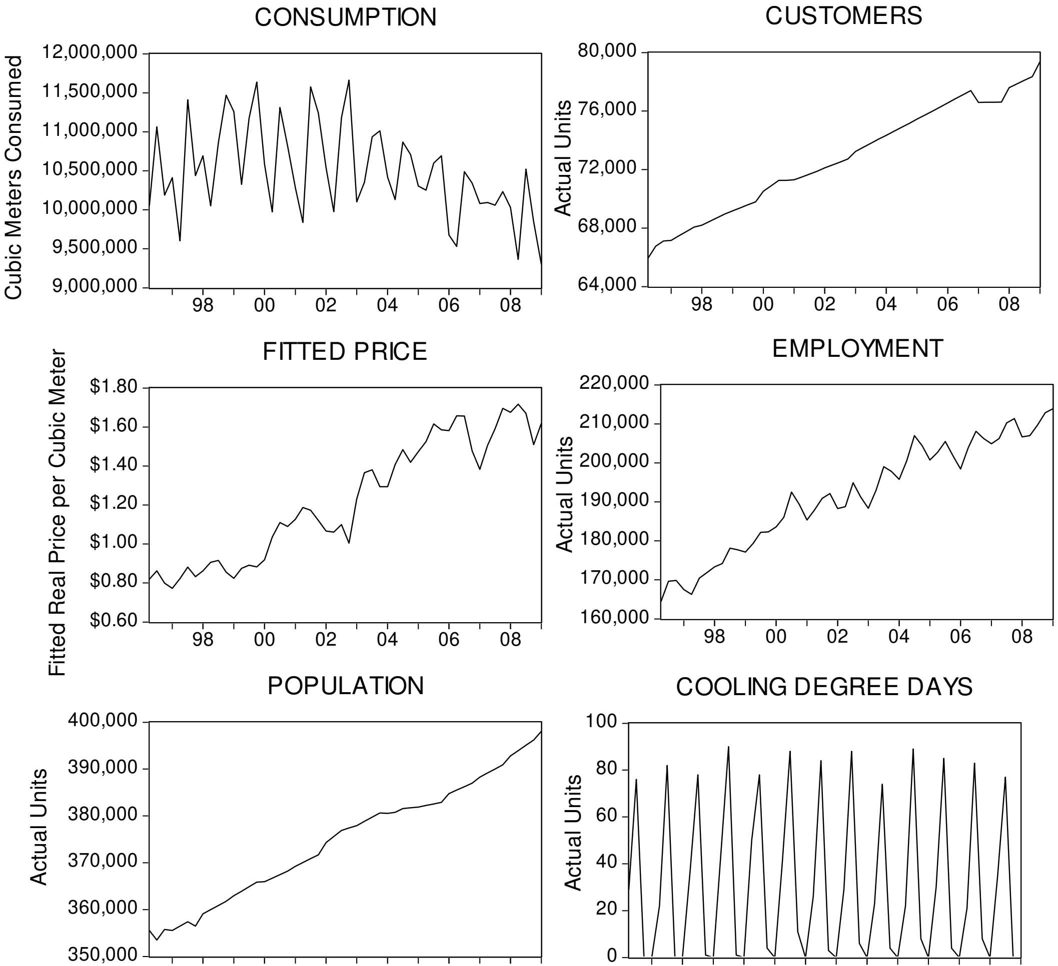

Figure 2. Residuals of the long-run cointegrating equation