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Tom Fullerton et al.
University of Texas at El Paso

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SHORT-TERM WATER CONSUMPTION PATTERNS IN CIUDAD JUAREZ

Tom Fullerton, UTEP CBA 236, El Paso, TX 79968-0543, tomf@utep.edu, 915-747-7747
Roberto Tinajero, UTEP CBA 236, El Paso, TX 79968-0543, rtinajero@utep.edu, 915-747-7775
Martha Patricia Barraza de Anda, Department of Economics, Universidad Autonoma de Ciudad Juarez, Ciudad Juarez, Chihuahua, Mexico, mbarraza@uacj.mx, 011-52-656-88-38-07

As a rapidly growing city in a semi-arid region, Ciudad Juarez faces several important resource management issues with regard to its municipal water system. Many of those issues deal with short-term management questions, especially during warm weather months when demand outstrips available groundwater supplies. Because of those considerations, and others, accurate analyses of monthly water demand for the Junta Municipal de Agua y Saneamiento (JMAS) water utility would be useful. To help achieve this objective, linear transfer function (LTF) models of per customer consumption and the total number of JMAS accounts are developed. In addition to parameter estimation, out-of-sample model simulations are also developed as an additional means for empirical reliability verification. The sample period covered is January 1997 to January 2004.

Contact: Tom Fullerton, UTEP Department of Economics & Finance, tomf@utep.edu, 500 West University Avenue, El Paso, TX 79968-0543, 915-747-7747, 915-747-6282

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Thomas M. Fullerton, Jr.*, Roberto Tinajero*, and Martha Patricia Barraza de Anda**

Author Affiliations

* Department of Economics & Finance, University of Texas at El Paso, El Paso, TX 79968-0543, Telephone 915-747-7747, Facsimile 915-747-6282, Email tomf@utep.edu

** Department of Economics, Universidad Autónoma de Ciudad Juárez, Email mbarraza@uacj.mx

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Abstract

Water utility planning efforts are becoming increasingly difficult throughout the world. Located in a semi-arid region, Ciudad Juárez, Mexico is a fast growing municipality that faces both physical infrastructure and water supply constraints. This paper examines monthly water consumption in Ciudad Juárez utilizing a linear transfer function procedure (LTF). Analysis is carried out for per customer usage and for the total number of municipal water system accounts. Models estimated for both series are subjected to a series of simulation benchmark tests. Findings suggest that water consumption in Ciudad Juárez reacts quickly to changes in economic and weather conditions. Out-of-sample simulation results are mixed. Per customer usage forecasts do not fare as well those for total customers relative to random walk benchmarks.

Key Words: Water consumption, applied econometrics, Mexico

JEL Category: Q25, Water Economics

Introduction

As a consequence of rapid population growth and increasing demand for water, many water utilities around the world complicated resource constraints. Management efforts are made more difficult because of large scale seasonal fluctuations in aggregate consumption levels. Those fluctuations generally cause specialized maintenance and administrative schedules to be developed for individual utilities as means for optimizing resources. Such steps also involve specialized supply management procedures in regions where seasonal demands consistently outstrip historical raw water sources (Fullerton 2005). For such areas, accurate forecasts of monthly consumption are of added importance.

Ciudad Juárez, Mexico is located in a semi-arid region and is one of many municipalities that face ongoing water constraints. Its highest volume of rainfall generally occurs between the months of July and October. Since 1997, rainfall has averaged only 22.1 centimeters (8.7 inches) per year. Ciudad Juárez is both the largest city in the State of Chihuahua. Because of its rapid growth, local policymakers face numerous budgetary issues regarding public infrastructure and overall water quality. Long-range projections have periodically indicated that fresh groundwater supplies from the aquifers that straddle the border are in danger of being depleted (Lloyd and Marston 1985; Chavez 2000).

Despite the constraints described above, short-term water consumption dynamics in Ciudad Juárez have not previously been modeled (Fullerton and Schauer 2001). Development of such a tool is potentially useful given the utility infrastructure required to handle seasonal consumption peaks. Accordingly, the objective of this paper is to analyze monthly water consumption patterns in Ciudad Juárez utilizing a linear transfer function procedure (LTF). Two separate equations are estimated, one for per customer consumption and other for total accounts in this border municipality. In addition, model simulations are employed to provide additional assessments of model reliability. Sample data for per customer consumption dates from January 2000 through December 2004. For total customer accounts, the sample begins in January 1997 and ends in December 2004.

Literature Review

Short-term forecasts are used in the operation and management of existing water systems (Martínez-Espiñeira 2002). To date, an extensive analysis of the short-run time series characteristics of urban water demand in Ciudad Juárez has not been completed. Such a task should be feasible for this border economy because many categories of monthly econometric models typically do not require large-scale data sets (Weber 1989).

Autoregressive moving average (ARIMA) models have previously been documented as helpful in examining the quantitative impacts with new policy initiatives and other changes to the economic landscape of the border region. Because they can incorporate independent regressor variables as arguments, transfer functions have been utilized for a wide range of practical applications. Accordingly, linear transfer function (LTF) analysis is a potentially useful methodology from among the various ARIMA techniques that are periodically applied to other public utility markets such as natural gas and electricity.

Two recent studies employ LTF techniques to model and forecast urban water markets that face similar water supply limitations to those of Ciudad Juárez. Fullerton and Nava (2003) estimate an LTF ARIMA model to examine monthly water consumption in Chihuahua City, Mexico. Similarly, Fullerton and Elías (2004) investigate water consumption patterns for El Paso, Texas. In addition to parameter estimates that exhibit good statistical traits, the LTF demand models for Chihuahua City and El Paso also generate out-of-sample forecasts that compare favorably to random walk benchmarks.

Data and Methodology

Data employed include total municipal water consumed, total water customer accounts, average price per cubic meter purchased, rainfall, and average ambient temperature. Municipal water data are available from Junta Municipal de Agua y Saneamiento de Ciudad Juárez (JMAS). Rainfall and average ambient temperature data are available from Consejo Nacional del Agua (CONAGUA). In addition, monthly maquiladora employment and the national industrial production index for Mexico are utilized as business cycle indicators. To deflate the average price series, the national consumer price index is employed. All three of the latter variables are available from Instituto Nacional de Estadística, Geografía, e Informática (INEGI). For modeling purposes, sample information for per customer consumption dates from January 2000 to December 2004. For total customer accounts, the sample begins in January 1997 and ends in December 2004.

Average price, maquiladora employment, industrial production, and the weather series are used as explanatory variables for per customer usage. Historical data for consumption and tariffs by rate class in Ciudad Juárez are not presently available. Monthly cubic meters consumed and the number of active accounts do allow a per customer consumption series to be assembled. To approximate a monthly price series, total water revenues are divided by total water consumed. The same approach has been used in areas where detailed public utility tariff information is not available or difficult to obtain (Shin 1985).

To deflate the price series, the monthly average price per cubic meter consumed is divided by the monthly consumer price index. Given that monthly income data do not exist for Juarez, monthly in-bond assembly employment and industrial production variables are utilized as proxies for prevailing economic conditions. To measure the impact of weather on water consumption, monthly rainfall in millimeters and the average monthly temperature in Celsius are employed. This approach is consistent with previous research in the water economics literature (Williams and Suh 1986; Martínez-Espiñeira 2002).

Per customer water consumption is the first estimated equation. The second is for the number of customers that purchase water from JMAS every month. If aggregate consumption is to be forecast, individual models for both variables can be utilized. Alternative approaches to this include directly modeling aggregate consumption with either the number of customers as one of its arguments (Williams and Suh 1986) or with past consumption as one of the regressors (Martínez-Espiñeira and Nauges 2004). As in other developing regions, the rapid rates of population growth that have characterized Ciudad Juárez in recent years creates substantial pressure to expand the urban water grid (Arimah 2005). Because of that, the number of JMAS customers is modeled independently of per customer usage.

The LTF method is an extension of the traditional transfer ARIMA approach involving several steps for identifying the relationships between the dependent variable of interest and the right-hand-side variables (Box and Jenkins 1976). Initially, autocorrelation functions (ACFs) are computed to verify whether each of the series in the sample is trend stationary. All non-stationary series at the 95 percent confidence interval are first-differenced to induce stationarity. To identify potential lag structures, cross correlation functions (CCFs) are calculated between the stationary component of an arbitrary dependent variable lags of an arbitrary stationary independent variable.

After an initial transfer lag structure between the dependent and independent variables is identified, the transfer ARIMA equation is estimated. Several rounds of diagnostic checking and re-estimation are generally required before selecting the final model (Box and Jenkins 1976). Under the LTF approach, remaining systematic movements not explained by the independent variables are then modeled using both autoregressive and moving average parameters.

The general specification for modeling water consumption per customer is summarized in Equation (1). Hypothesized relationships between the regressors and the dependent variable appear in the parentheses under each of the independent variables. Lags for each of the input series, the autoregressive, and moving components are allowed to vary. All variables are expressed as stationary components of the original series.

$$w_t = \theta_0 + \underset{(-)}{\sum_{a=1}^{A} a_a p_{t-a}} + \underset{(+)}{\sum_{b=1}^{B} b_b mqm_{t-b}} + \underset{(+)}{\sum_{c=1}^{C} c_c mxip_{t-c}} + \underset{(-)}{\sum_{d=1}^{D} d_d rfm_{t-d}} + \underset{(+)}{\sum_{e=1}^{E} e_e tmp_{t-e}} + \sum_{i=1}^{p} \phi_i w_{t-i}$$
$$+ \sum_{j=1}^{q} \theta_j u_{t-j} + u_t \qquad (1)$$

where:
w_t = Ciudad Juárez water usage per customer in month *t*, 1000 cubic meters,
p_t = Average real price per cubic meter in month *t*,
mqm_t = Ciudad Juárez non-seasonally adjusted, maquiladora employment in month *t*,
$mxip_t$ = Industrial production index for Mexico in month *t*, 1993 = 100,
rfm_t = Monthly Ciudad Juárez rainfall in millimeters,
tmp_t = Average Ciudad Juárez temperature Celsius each month.

Similarly, the general specification for the number of JMAS water utility customers is given by Equation (2). Once more, hypothesized relationships between the independent variables and the left-hand side variable are summarized in the parentheses that appear under each of the regressors. As with usage per customer, lags for each of the input variables, the autoregressive, and moving average components are allowed to vary. The two input series are included because monthly population estimates do not exist for this border city, but demographic expansion there is largely driven by in-migration flows in response to economic conditions and job opportunities.

$$cust_t = \theta_0 + \underset{(+)}{\sum_{a=1}^{A} a_a mqm_{t-a}} + \underset{(+)}{\sum_{b=1}^{B} b_b mxip_{t-b}} + \sum_{i=1}^{p} \phi_i cust_{t-i} + \sum_{j=1}^{q} \theta_j v_{t-j} + v_t \qquad (2)$$

where:
$cust_t$ = Total JMAS water customers in month t,
mqm_t = Ciudad Juárez non-seasonally adjusted, maquiladora employment, 1000s, in month t,
$mxip_t$ = Industrial production index for Mexico in month t, 1993 = 100.

Given that good statistical traits do not guarantee out-of-sample simulation accuracy, several benchmark simulations are utilized to further assess model reliability (McCloskey and Ziliak 1996; Inoue and Kilian 2004). In addition to descriptive measures such as root mean square error (RMSE) and Theil inequality U-statistics, two formal tests are also applied to the forecast data. One is the nonparametric test proposed by Diebold and Mariano (1995). The second is a forecast error differential F-test (Ashley et al. 1980).

Following parameter estimation, a 24-month *ex post* forecast exercise is conducted. First, a sub-sample estimation period is defined with December 2002 as the last period for which observations are available. Model simulations are then conducted for the 12-month period from January 2003 to December 2003. Next, the estimation period is expanded by one month to January 2003 and the forecast period is rolled forward to February 2003 through January 2004. This procedure is repeated 24 times through December 2004. This results in 24 one-month water consumption and 24 one-month total accounts forecasts, 23 two-month forecasts, 22 three-month forecasts, and so forth to 12 twelve-month forecasts.

To investigate simulation accuracy, random walk forecasts for both dependent variables are compiled to provide comparative benchmarks. For per customer water consumption, a series that does not exhibit strong growth, the latest available historical observation is used as the prediction for all periods falling beyond the sample estimation range. For the number of water utility customers, a series that has trended upward in recent years, the last available percentage change is used to generate a random walk with drift prediction for all months beyond the end of the sample estimation range. Benchmark extrapolations compiled in this manner have previously been shown to be accurate relative to econometric forecasts previously compiled for the borderplex regional economy where Ciudad Juárez is located. The out-of-sample simulations generated by the LTF models and the random walk procedures are then segregated into step-length forecasts. The segregated data for both methodologies are then compared to actual JMAS water utility data for January 2003 through December 2004.

Prediction errors for both sets of forecasts are utilized to calculate root mean squared errors (RMSE) and Theil inequality (U) coefficients for all 12 simulation step-lengths (Pindyck and Rubinfeld 1998). While RMSE estimates are positively unbounded, U coefficients vary between 0 and 1. When U=0, a perfect simulation fit is obtained. On the other hand, if U = 1, the predictive performance of the model is as bad as it can possibly be (Pindyck and Rubinfeld 1998).

U-statistics are frequently employed in econometric accuracy rankings. Although they have been shown to provide reliable rankings, these measures are descriptive and have no statistical significance associated with them. If the difference over time between the RMSEs for the LTF and random walk forecasts is covariance stationary, then another accuracy measure can be utilized. Diebold and Mariano (1995) propose a non-parametric t-test to examine which extrapolation approach is most accurate. That approach takes the difference between the RMSEs for the Random Walk and LTF forecasts and regresses them against an intercept term.

The Diebold and Mariano (1995) procedure assumes that the sample size is large. This assumption is clearly not satisfied for the data set that currently exists for urban water demand in

Ciudad Juárez. Given that, another method for accuracy comparisons for per customer consumption and the total number of water bills is also deployed. A regression equation using forecast error differentials (Ashley et al. 1980) is also estimated. The null hypothesis tested for the second approach is whether the intercept and slope coefficients are both equal to zero. Rejection of the null hypothesis implies that the LTF forecasts are statistically more accurate the corresponding set of random walk benchmarks.

Empirical Results

Estimation results from the LTF modeling procedure for per customer consumption match well with general expectations. Coefficient signs for the independent variables are as hypothesized and all but one satisfy the 5-percent significance criterion. In contrast to the earlier studies for El Paso (Fullerton and Elías 2004) and Chihuahua City (Fullerton and Nava 2003), multicollinearity does not appear to be a problem for the Ciudad Juárez municipal water data.

Maquiladora employment affects water consumption with a lag of 5-months while Mexican industrial production index enters the equation with lag of 14-months. Rainfall and monthly average outdoor temperature are both included with 1-month lags. These reaction times are similar to those documented for El Paso and Chihuahua City. Regional climatic and industrial commonalities shared between those metropolitan economies and Ciudad Juárez make those outcomes plausible. To correct for the effect of serially correlated residuals, a fourth-order autoregressive parameter and a sixth-order moving average term are also included in the model specification.

Although the per customer water data have been differenced, the coefficient of determination for the dependent variable is fairly high, R-squared = 0.82. A pseudo R-squared coefficient is also calculated after transforming the fitted data for the dependent variable back to level form. Once the fitted estimates are in level form, a correlation coefficient is calculated between those data and the actual historical data. The correlation coefficient is raised then to the power of two yielding to the pseudo R-squared estimate. By this measure, the explanatory power of the model increases to nearly 92 percent of the variation in the left-hand side variable for the sample period in question. A low Q-statistic generated for the per customer water consumption residuals suggests that the equation succeeds in accounting for systematic movements in the dependent variable.

Parameter estimation output for the number of JMAS billing accounts reflects the rapid growth of the water grid in Juarez and is underscored by a statistically significant, and positive, constant term. The magnitude of that coefficient indicates that, for the 1997-2004 sample period, the number of hook-ups expanded by roughly 1,612 accounts per month. Maquiladora employment enters the equation with lags of 6, and 18 months. For every 1,000 new in-bond manufacturing jobs, approximately 68 new water accounts are added to the system within 18 months. To correct for serial correlation, a twelfth-order autoregressive parameter and an eighth-order moving average coefficient are also included. Once more, the Q-statistic indicates that the model does not overlook any systematic variation in the monthly number of urban water customers. The pseudo R-squared coefficient indicates that the model explains more than 99 percent of the variation in the dependent variable during the period in question.

As previously noted, strong in sample correlations do not always guarantee model simulation accuracy. Out-of-sample extrapolations for the LTF per customer water model are also analyzed. In contrast with other multi-period predictions, the LTF consumption RMSEs and U-statistics do not increase as monotonic functions of simulation step-length. Encouragingly, the U-statistics for this model remain below 0.1 for all 12 sets of months-ahead forecasts.

Random Walk per customer water consumption out-of-sample predictive accuracy is assessed as well. For the first and last three step-lengths, the Random Walk RMSEs and Theil U-statistics are smaller than those calculated for the LTF equation. For steps 2 through 9, the Random Walk accuracy is less precise than that of the LTF consumption model.

To examine whether the accuracy differences uncovered are statistically significant, a non-parametric t-test is performed using the specification described above. The constant term is greater than zero, indicating that the LTF forecasts are more accurate than those of the Random Walk. However, the computed t-statistic for the constant term is not significant at the 5-percent level. This result implies that the LTF and Random Walk RMSEs for per customer water usage are not statistically different from each other (Diebold and Mariano 1995). Because only a relatively small number of observations are available for the analysis, additional testing is warranted.

A second set of regression tests examines whether the mean square errors of the per customer usage predictions are statistically different from each other (Ashley et al. 1980). The null hypothesis of mean square error equality among the two sets of forecast errors are only rejected for 3 of the 12 individual step-lengths. Furthermore, when the simulation errors are pooled across all period-ahead forecasts, the null hypothesis also fails to be rejected. The preponderance of evidence generated, thus, indicates that the Random Walk per customer usage forecasts are statistically competitive with the LTF extrapolations.

Total water accounts simulation accuracy assessments are also examined. The LTF and the Random Walk predictions are both seen to be fairly precise and exhibit good simulation characteristics. However, the LTF equation projections obtain noticeably lower RMSEs at all twelve step-lengths. In addition to exhibiting U-statistics below 0.01 at all 12 step-lengths, the covariance proportion of the LTF simulations are above 0.93 for the first nine periods ahead.

The arithmetic difference approach is also deployed to address whether there is a statistically significant difference between LTF and Random Walk out-of-sample account simulations. The intercept term for the arithmetic difference model is greater than zero and statistically significant at the 5-percent level. That implies that the LTF RMSEs for the total number of water bills are statistically smaller than those obtained from the Random Walk with drift procedure for this variable (Diebold and Mariano 1995).

The error differential regression outcomes also suggest that the LTF forecasts of total water customers of JMAS are relatively more accurate than those of the benchmark. For nine of the step-lengths, the LTF RMSEs are smaller than those of the Random Walk extrapolations by a statistically significant margin (Ashley et al. 1980). In only three cases does the null hypothesis of mean square error equality fail to be rejected. For the pooled sample across all forecast step-lengths, the results also indicate that the LTF forecasts for the JMAS customer base are statistically more accurate than the Random Walk out-of-sample simulations.

Policy Implications

The findings discussed above confirm that good in-sample fits do not necessarily guarantee accurate forecast simulations. Given the mixed results associated with the simulation properties of the models, inferences drawn with respect to the conduct of short-term water management practices in Ciudad Juárez must be treated with some caution. However, the fact that the per customer usage in-sample and out-of-sample empirical results are not in complete agreement with each other does not imply that forecast and other applications with the LTF models for this public utility are automatically suspect (Inoue and Kilian 2004).

Similar to other regional water studies, the estimation results indicate that Juarez water consumption will increase in response to favorable economic conditions. JMAS staff planners should monitor local business cycle developments. For example, rapid payroll growth in the maquiladora industry tends to attract migrants from other regions in Mexico and increase the demand for new infrastructure development. Accordingly, JMAS will face greater pressure to obtain financial resources to support such investment outlays. Given that the in-bond assembly sector and the national economy are both expanding in Mexico, JMAS authorities may lessen those financial pressures by adopting a combination of impact fees and higher rates to allow quicker expansion of the existing system.

Because per meter consumption levels respond quickly to price hikes, JMAS officials may want to consider temporary rate surcharges when facing supply shortages caused by droughts or other factors. Although rate increases do not show up on consumer bills until after a month after the actual usage has occurred, the model lag structure points to forward-looking expectations behavior on behalf of JMAS customer base. As previously documented, JMAS customers monitor rate increase announcements very closely (Castañón 2005). That behavior can be exploited in the context of temporary surcharges to encourage reductions in water consumption and help mitigate the severity of potential supply constraints.

Decision makers at JMAS can also utilize prevailing weather patterns to modify existing supply management procedures. Warmer temperatures lead to greater consumption. To offset that reaction, seasonal surcharges could be enacted as a means for generating additional financial resources to support infrastructure investment. Because rainfall also leads to quick reductions in consumption levels, extended periods of sub-par precipitation would also be candidates for temporary usage restrictions and/or emergency surcharges.

Capital expenditures and maintenance programs are forcing permanent rate increases to be instituted by water utilities throughout Mexico (Castañón 2005). Estimates reported here indicate that such increases will lead to per meter consumption declines for the JMAS water utility system. Simulations with these types of dynamic models can provide insights with respect to the timing and sizes of those responses to prospective price hikes. Planning for rate increases will potentially benefit from also taking into account prevailing economic and weather conditions. Similarly, investigating how those conditions interact with higher tariffs should allow JMAS planners to achieve better insights to revenue and volume impacts.

Conclusion

This paper uses time series analysis to investigate the behavior of monthly water consumption in the Ciudad Juárez metropolitan economy. Two separate equations are estimated, one for per customer usage and the other for total municipal water system accounts. Data employed include monthly time series of per meter water consumption, average monthly temperatures in degrees Celsius, rainfall in millimeters, average real price per cubic meter, maquiladora employment, and the national industrial production index for Mexico. Results obtained are quantitatively similar to those reported for other semi-arid metropolitan economies using time series econometric procedures. Monthly water consumption reacts quickly to changes in both economic and weather variables. Increases in economic activity also lead to increases in the number of hook-ups to the water system. All of the estimated coefficients exhibit the hypothesized arithmetic signs and most are statistically significant.

Simulations generated using both equations are also compared to Random Walk benchmarks for testing out-of-sample forecast accuracy. A 24-month *ex post* forecast exercise is completed, with predicted values sorted into one- through twelve step-length sets. For per customer usage, the simulation results are mixed and indicate that the Random Walk forecasts are often more accurate than those generated with the LTF equation. For customer accounts, out-of-sample simulations from the time series equation are shown to be statistically more precise than their benchmark counterparts for most of the individual step-lengths.

Additional research using data from other urban water markets would be helpful. Because data requirements are not excessive, replication of these steps for other utilities should be feasible. Where data permit, future empirical analyses of metropolitan water consumption patterns could focus on single-family, multi-family, commercial, and industrial customer categories. Given the levels of regional uncertainty surrounding hydrologic resources, the latter may provide additional insights that can improve future management efforts.

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