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REGIONAL ECONOMETRIC ASSESSMENT OF AGGREGATE WATER CONSUMPTION TRENDS[1]

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ABSTRACT Regional water availability is rapidly becoming an issue throughout many areas of the world. To accurately gauge the severity of potential supply shortfalls requires quantitative assessment of aggregate consumption trends. Regional econometric modelling and forecasting analysis offers one means by which this objective may be attained. This requires partially expanding the traditional modelling framework to include water customer and per capita consumption trends by rate class. Empirical results from the El Paso – Ciudad Juárez borderplex forecasting model are presented that indicate that regional models can be utilized to accomplish such steps in an effective manner.

1. INTRODUCTION

Population growth and economic factors are causing water shortages and quality issues to emerge in many regions of the world. As might be expected, this general observation is especially applicable to many arid and semi-arid areas. Consumption trends are such, however, that long-term water availability concerns have also surfaced in geographic realms that usually observe ample rainfall levels every year (Anonymous, 2000). Given the levels of regional uncertainty surrounding this important resource, a natural question arises in terms of the quantitative tools available to policy analysts and planners.

This paper investigates the applicability to aggregate water consumption analysis of a standard device long relied upon in regional science and urban economics. More specifically, the usefulness of regional econometric modelling is assessed with respect to water use. As discussed below, these categories of models are commonly utilized to examine multiple sectors of many different regions. Commonly included in such constructs are demographics, personal income, employment, residential construction, and retail sales activity. In the

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absence of binding data constraints, there exists no compelling reason why coverage in these models cannot be extended to encompass water usage for any given area. Such an effort is attempted for the El Paso metropolitan economy, which is situated adjacent to the Mexican border in the southwestern quadrant of the United States.

Subsequent sections of the paper are as follows. A short discussion of regional econometric modelling analysis and water consumption research is provided in the second section. A brief comparison of the classical regional modelling approach with the borderplex framework follows. Empirical characteristics of the borderplex water equations are reviewed in the fourth section. A summary and suggestions for future research are provided in the conclusion.

2. REGIONAL ECONOMETRIC MODELLING AND WATER RESEARCH

Systems of equations approaches to econometric modelling, forecasting, and policy analysis have been extensively applied to regional and metropolitan economies for many years (Bolton, 1985). Coverage in these models varies, but generally revolves around population, employment, income, retail sales, and residential construction (Hunt and Snell, 1997). Reflective of data constraints, regional models are typically arranged in satellite arrays such that metropolitan models are recursively linked to state models, and state models are themselves recursively dependent upon national models (Klein, 1969). These models are used in a wide variety of public policy (Coomes, Olson, and Merchant, 1991; Fullerton, 1987; Plaut, Preuss, and Ferguson, 1996), commercial (Ellis, 1998; Prybolsky, 1998; Zandi, 1999), and academic research settings (Kim, 1995; West and Fullerton, 1996; Fullerton and West 1998).

Overall flexibility has allowed large scale econometric models to be applied to a wide range of regional issues, but these efforts have not generally included water consumption analysis. Fortunately, the analysis of regional demand for water is replete with a well-documented record of econometric research results. Many of these studies focus on residential water consumption patterns (Camp, 1978; Whitcomb, Yingling, and Winer, 1993; Michelsen, McGuckin, and Stumpf, 1998; Pint 1999). Demand estimation research has frequently focused on model form and rate measure (Billings, 1982; Chicoine and Ramamurthy, 1986; Nieswiadomy, 1992; Bishop and Weber, 1996). The simultaneous impacts of residential and commercial growth have also been assessed (Carver and Boland, 1980; DeKay, 1985). Given the importance of landscaping choices, climatic variables have played central roles in many studies of aggregate residential water consumption (Agthe and Billings, 1980; Weber, 1989; Michelsen, McGuckin, and Stumpf, 1998; Pint, 1999).

It is readily apparent that substantial effort has been devoted to the analysis of regional and urban economies via large scale modelling frameworks that allow simultaneous assessment of multiple segments of those areas. It is equally apparent that much research has also been carried out with respect to cross sectional analysis of metropolitan residential water usage. Comparatively less energy has been directed toward merging these two strands of the literature under a common umbrella. Given the emergence of regional water conflicts in many areas of the world, this is a potentially important line of research. One approach toward this goal is illustrated below in the context of a border metropolitan economy on the southern boundary of the United States.

3. BORDERPLEX MODEL ATTRIBUTES

The traditional arrangement for metropolitan econometric forecasting systems utilizes a top-down arrangement, reflecting the fact that urban business cycles are generally driven by their national counterparts (Klein, 1969). It also reflects the fact that greater detail is available for national economic data than for state data, and greater detail is provided at the state level than at the county or municipal levels of aggregation (Bolton, 1985; Hunt and Snell, 1997). The classical satellite modelling arrangement expresses metropolitan variables as functions of both state and national exogenous variables, with state variables expressed as functions of national variables. Generally, there is very little feedback from regional to national economies in the traditional approach to metropolitan forecasting and policy analysis.

Borderplex economies such as El Paso - Ciudad Juárez, adjacent to each other on the boundary between the United States and Mexico, are affected by two national business cycles and a local metropolitan feedback process (Fullerton, 2001). On the north side of the Rio Grande river that serves as the line of demarcation, El Paso is also affected by a regional business cycle unique to Ciudad Juárez. Furthermore, the El Paso metropolitan economy, defined by the United States Department of Commerce as El Paso County, enjoys close commercial and industrial ties with four states that account for roughly one-third of national output in the United States. From a modelling perspective, the numerous economic linkages between El Paso with Arizona, California, New Mexico, and Texas obviate the need for an intermediate set of exogenous regressors that reflect home state regional business cycle factors alone. Figure 1 summarizes the flow chart strategy utilized to model the borderplex economy.

Recent economic history along the Mexican border in Texas underscores the basic logic behind Figure 1. The “Tequila Effect” peso devaluation of December 1994 precipitated a severe recession in Mexico that lasted throughout 1995 and into the first quarter of 1996. Losses in Mexican consumer purchasing power directly contributed to the closure of approximately 60 retail outlets in El Paso. Simultaneously, however, other segments of the local economy benefited from the rapid expansion in “maquiladora” twin plant manufacturing activities. The latter expanded both output and employment in response to the lower dollar equivalent wage bills that temporarily resulted from the devaluation (Vargas, 1995; Gould, 1996; MacLachlan and Aguilar, 1998).

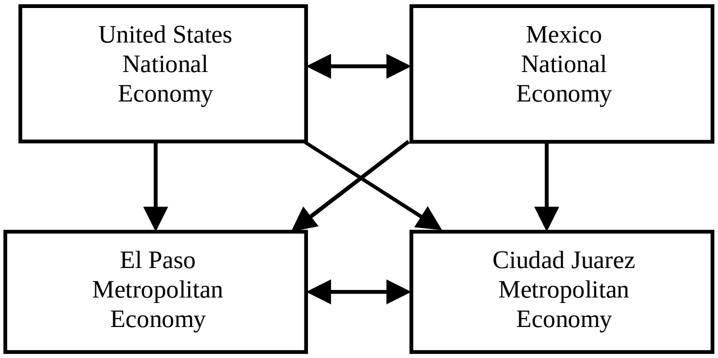

Figure 1: Border Region Econometric Forecasting Model

Because of the strong maquiladora presence within its economic base, the 1995 recession was less severe in Ciudad Juárez than it was in Mexico as a whole (Fullerton and Schauer, 2000). In contrast, while some segments of the El Paso business sector were supported by greater twin plant activity, the tequila effect, military downsizing at Ft. Bliss, and energy sector corporate mergers caused the border economy to lag the rest of the Texas state economy. A fully integrated econometric forecasting system for either side of the border should, therefore, take into account the endogeneity inherent in the cross-border economic ties between El Paso and Ciudad Juárez. Figure 1 also depicts the business cycle feedback that exists between the two national economies, as well as the direct linkages from industrial activity in the United States to the "maquiladora" in-bond assembly plants on the south side of the international boundary.

Even in the presence of international business cycle linkages, Figure 2 illustrates that the structure of the endogenous equation system comprising the borderplex model is similar to that associated with non-border metropolitan models (Bolton, 1985; Hunt and Snell, 1997). Two principal features distinguish border and non-border models. As shown in the diagrams, a variety of international business cycle data are used as independent variables in many border region equation blocks. Also, border models will generally contain completely separate blocks of equations designed to incorporate impacts and trends generated by international commerce (Cobb, Molina, and Sokulsky, 1989; Fullerton, 2001). The relationship of such equation blocks to the El Paso model can be seen in Figure 2. Port city econometric models for areas such as Miami also contain vestiges of these elements (West and Fullerton, 1996), but generally to a lesser degree than that associated with the borderplex forecasting system.

The El Paso model is used for a variety of purposes. The most important is business trend monitoring and economic forecasting for the international borderplex region (Fullerton, 2000). A principal advantage associated with the

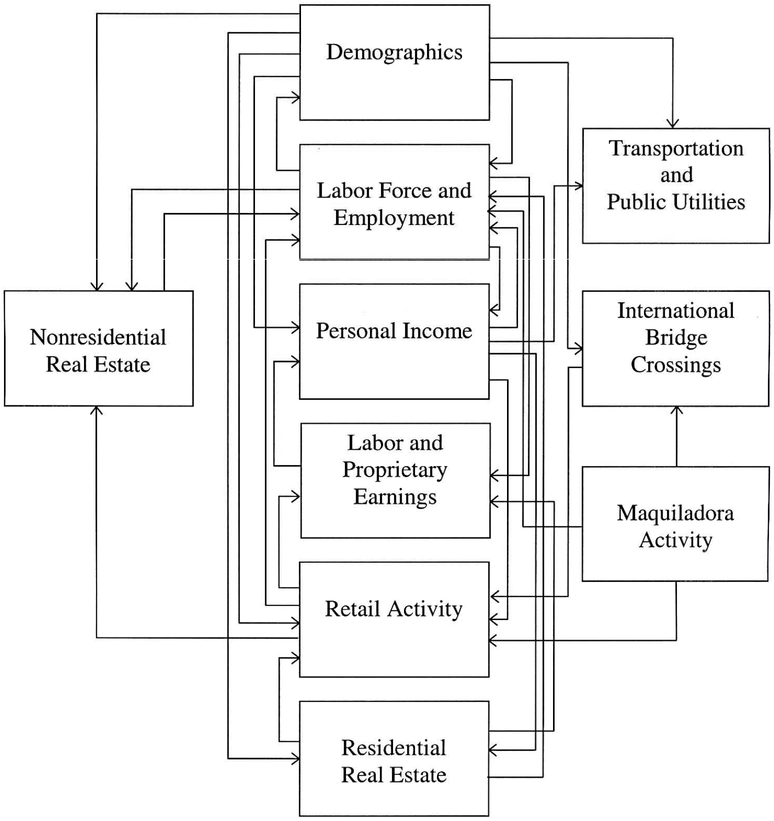

Figure 2: Borderplex Econometric Model - Endogenous Variable Equation Blocks

model is that it provides information regarding border business conditions in a framework that explicitly models international aspects of the local economy. The borderplex model is also used in a variety of public policy analysis exercises such as the provision of simulation data utilized in testimony provided to the Texas State Senate regarding NAFTA adjustment efforts on the border.

Sectoral coverage in the model is somewhat broad. The ten separate equation blocks outlined in Figure 2 include demographics, employment, income, labour earnings by industrial activity, retail sales, residential real estate, non-residential construction, maquiladora activity, northbound international border crossings, and transportation and public utilities. As shown in the diagram, the structure of the model is highly simultaneous with numerous direct and indirect feedback loops connecting the various sectors of the model. It should be noted, however, that only recursive linkages exist between the central core of the model and the transportation and public utility, non-residential construction, and international bridge crossing equation blocks. The latter is partially due to data constraints in the form of statistical degrees of freedom and cost of production information limits. It should not, therefore, be interpreted as reflecting non-central roles of any of those sectors in the metropolitan economy. As more econometric information becomes available, it is likely that statistically significant endogeneity will become apparent between these equation blocks and the other segments of the border region model.

The current version of the border forecasting system contains 180 equations (Fullerton, 2001). Water equations are included within the transportation and public utility block. Included in the 180 equations are 35 identities and 145 stochastic equations. Annual frequency data are used for parameter estimation, with most series spanning the three-decade period from 1970 to 2000. Subsequent to initial model development in 1997, multiple specifications have been tested for most of the regression equations. Of the 145 fitted results ultimately selected, most exhibit good statistical traits, but nearly all contain at least partial specification and/or empirical flaws. Results associated with the water consumption equations and the design of that model sub-sector are detailed below.

4. WATER EQUATION EMPIRICAL RESULTS

Annual frequency data are used to estimate all of the equations in the borderplex model. Water consumption in El Paso is divided into four broadly defined rate classes: residential single-family, residential multi-family, commercial and industrial, and not elsewhere classified. The latter user category exhibits the most variability with respect to annual per capita usage patterns, but could not be broken into more precisely defined consumer groups as a consequence of data constraints. For Ciudad Juárez, two equations are included: total meter connections and total water consumption. In all, seventeen equations comprise the water block of the borderplex model. They include six identities and eleven stochastic specifications.

Among the regression equations, five require some form of autocorrelation correction. That five of the eleven water model stochastic specifications require serial correction at least partially reflects widespread data constraints that also affect other categories of regional econometric modelling analysis (Fullerton and West, 1998). Comments received from seminar participants from the United States, Mexico, and other countries indicate that such information limitations are also likely to hold true on a time series basis for water utilities in many other geographic areas. Although a careful literature review was undertaken to help minimize such mistakes, specification error in the model design itself may also play a role in the autocorrelation correction requirements shown below.

The strategy utilized to model annual City of El Paso water demand calculates total gallons per user class as the products of the respective numbers of customers with the corresponding numbers of gallons consumed per customer.

Eight regression equations thus result with respect to meter connections and per customer consumption. A ninth regression equation is utilized to model an effective average rate variable. Similar detail is not available at present for the southern half of the borderplex, but limited statistical analysis has been conducted for the meter hook-up and aggregate consumption series reported in Escudero (2000). Table 1 lists the variable names and their individual definitions.

Similar to Billings (1982) and Michelsen, McGuckin, and Stumpf (1998), linear specifications are utilized since data transformation was not found to generate improvements in the empirical characteristics of the output.

General specifications and statistical output associated with each of the individual regression equations are reported in Table 2. Parameter estimation is carried out using a non-linear ARMAX procedure (Pagan, 1974). Selection of the ARMAX procedure is dictated by the tendency for regional econometric modelling systems to be characterized by a variety of data generating processes. The ARMAX estimator can handle autoregressive, moving average, as well as mixed processes. All three processes are present in the econometric results described herein.

Equations 1 through 6 are identities for total meter connections and total gallons consumed. Equation 7 models single-unit residential meters as a function of the single-family housing stock in El Paso. While explaining 99 percent of the in-sample variation in the dependent variable, inclusion of a first order autoregressive parameter is required to correct for serially correlated residuals. Equation 8 similarly models multi-unit residential meter connections as dependent upon the multi-family housing stock. Autocorrelation correction is required for this equation, also. It is accomplished by inclusion of a first-order autoregressive parameter and a second-order moving average parameter.

One of the most difficult data limitations uncovered in this research was the absence of water rate time series information by user-class for El Paso. To overcome this problem, total water and sewer revenues were divided by annual gallons consumed to provide an approximate price estimate for the utility as a whole (see Archuleta, 1998). This procedure is identical to the one that is successfully employed in Florida by Whitcomb, Yingling, and Winer (1993). Obviously, this approach prevents implementing the type of marginal block-rate specifications that have proven useful in cross section studies for other metropolitan areas (Billings, 1982; Pint, 1999). It may not represent an insurmountable problem, however, as numerous studies have uncovered evidence that utility customers often respond to average prices rather than marginal prices (Shin, 1985; Nieswadomy and Molina, 1991; Chicoine and Ramamurthy, 1992; Nieswiadomy, 1992; Michelsen, McGuckin, and Stumpf, 1998). Replication of the tests utilized in those studies is not currently feasible for El Paso, but may be for other regional markets.

Table 1. Border Model Water Variable Mnemonics

Series	**Definition**
CJWMTR	Ciudad Juárez, Total Water Meters, 1000s
CJWTR	Ciudad Juárez, Total Water Consumption, Million Cubic Meters
ELWGT	El Paso, Total Water Consumption, Billion Gallons
ELWGRS	El Paso, Residential Single-Family Water Consumption, Billion Gallons
ELWGRM	El Paso, Residential Multi-Family Water Consumption, Billion Gallons
ELWGCI	El Paso, Commercial & Industrial Water Consumption, Billion Gallons
ELWGNEC	El Paso, Not Elsewhere Classified Water Consumption, Billion Gallons
ELWBT	El Paso, Total Water Meters, 1000s
ELWBRS	El Paso, Residential Single-Family Water Meters, 1000s
ELWBRM	El Paso, Residential Multi-Family Water Meters, 1000s
ELWBCI	El Paso, Commercial & Industrial Water Meters, 1000s
ELWBNEC	El Paso, Not Elsewhere Classified Water Meters, 1000s
ELWPRS	El Paso, Residential Single-Family Per Customer Water Consumption, 1000 Gallons
ELWPRM	El Paso, Residential Multi-Family Per Customer Water Consumption, 1000 Gallons
ELWPCI	El Paso, Commercial & Industrial Per Customer Water Consumption, 1000 Gallons
ELWPNEC	El Paso, Not Elsewhere Classified Per Customer Water Consumption, 1000 Gallons
ELWRATE	El Paso, Average Water Rate, Dollars per 1000 Gallons
ELWRAIN	El Paso, Annual Rainfall, Inches
ELWHEAT	El Paso, Annual Number of Days with Temperatures Above 90 Degrees F
ELWDV	El Paso, Water Restrictions Dummy Variable, 1959 - 1989 = 0, 1990 forward = 1
ELBSN	El Paso, Number of Business Establishments, 1000s
ELHSSTK	El Paso, Housing Stock, Single-Family Units, Thousands
ELHMSTK	El Paso, Housing Stock, Multi-Family Units, Thousands
ELMPVT	El Paso, Employment, Private Sector Only, 1000s
ELPPOP	El Paso, Population, 1000s
ELYP	El Paso, Total Personal Income, Billion Dollars
PDCCE	United States, Personal Consumption Expenditures Implicit Price Deflator, 1996 = 100
PDIGDP	United States, Gross Domestic Product Implicit Price Deflator, 1996 = 100

Table 2. Border Model Water Equation Listings and Empirical Estimation Results

Equations 1 - 6 are Identities
Equations 7 - 17 are Stochastic

EQUATION 1 Total Water Meters, City of El Paso, 1000s
ELWBT = ELWBRS + ELWBRM + ELWBCI + ELWBNEC

EQUATION 2 Residential Single-Family Water Consumption, Billion Gallons
ELWGRS = ELWBRS * ELWPRS / 1000

EQUATION 3 Residential Multi-Family Water Consumption, Billion Gallons
ELWGRM = ELWBRM * ELWPRM / 1000

EQUATION 4 Commercial &Industrial Water Consumption, Billion Gallons
ELWGCI = ELWBCI * ELWPCI / 1000

EQUATION 5 Not Elsewhere Classified Water Consumption, Billion Gallons
ELWGNEC = ELWBNEC * ELWPNEC / 1000

EQUATION 6 Total Water Consumption, City of El Paso, Billion Gallons
ELWGT = ELWGRS + ELWGRM + ELWGCI + ELWGNEC

EQUATION 7 City of El Paso, Residential Single-Family Water Meter Connections
ELWBRS = f(ELHSSTK)

Non-linear Least Squares

Annual data for 27 periods from 1973 to 1999

elwbrs =	0.85959*	elhsstk	24.8579		
	(18.9908)		(3.37297)		
Sum Sq	25.2271	Std Err.	1.0252	LHS Mean	100.919
R Sq.	0.9974	R Bar Sq	0.9972	F 2, 24	4566.40
D.W.(1)	1.2787	D.W .(2)	1.6007		
AR_0 =	0.75331*AR_1				
	(6.33764)				

Table 2 *(contd)***.** Border Model Water Equation Listings and Empirical Estimation Results

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EQUATION 8 City of El Paso, Residential Multi-Family Water Meter Connections
ELWBRM = f(ELHMSTK)
Non-linear Least Squares
Annual data for 27 periods from 1973 to 1999

elwbrm = 0.01372* elhmstk +3.98742
(2.26811) (11.3416)

Sum Sq.	0.0695	Std Err	0.0550	LHS Mean	4.7141
R Sq.	0.9422	R Bar Sq	0.9346	F 3, 23	124.880
D.W.(1)	1.7530	D.W.(2)	2.1206		

AR_0 = 0.75187*AR_1
(5.67536)

MA_0 = 0.38675*MA_2
(2.70232)

EQUATION 9 City of El Paso, Commercial & Industrial Water Meter Connections
ELWBCI = f[ELWBCI.1, ELBSN.1]
Non-linear Least Squares
Annual data for 35 periods from 1965 to 1999

elwbci = 0.88382* elwbci.1+0.05050* elbsn.1 +0.51328
(23.6352) (2.64843) (5.19615)

Sum Sq.	0.3818	Std Err.	0.1109	LHS Mean	6.9736
R Sq.	0.9945	R Bar Sq.	0.9939	F 3, 31	1860.56
D.W.(1)	1.5734	D.W.(2)	1.7805	H	1.0714

MA_0 = 0.71811*MA_1
(4.91060)

EQUATION 10 City of El Paso, Not Elsewhere Classified Water Meter Connections
ELWBNEC = f(ELWBNEC.1, ELPPOP.1)
Non-linear Least Squares
Annual data for 21 periods from 1979 to 1999

elwbnec = 0.84194* elwbnec[-1]+ 0.01235* elppop[-1] - 5.74240
(7.65350) (2.12845) (2.02660)

Sum Sq.	7.0849	Std Err.	0.6274	LHS Mean	5.6699
R Sq.	0.9800	R Bar Sq.	0.9778	F 2, 18	441.411
D.W.(1)	2.4516	D.W.(2)	1.5880	H	-1.5568

Table 2 ***(contd)*****.** Border Model Water Equation Listings and Empirical Estimation Results

EQUATION 11 City of El Paso, Average Water Rate, Dollars per 1000 Gallons
ELWRATE = f(ELWRATE.1, PDIGDP.1)
Nonlinear Least Squares
Annual data for 23 periods from 1977 to 1999

elywrate =	0.42685*	elwrate.1 +	0.01441*	pdigdp.1 +	0.08945
	(2.70621)		(3.53148)		(2.71814)
Sum Sq.	0.0901	Std Err.	0.0671	LHS Mean	1.2568
R Sq.	0.9823	R Bar Sq.	0.9805	F 2, 20	554.961
D.W.(1)	1.8873	D.W.(2)	2.1634	H	-0.0774

EQUATION 12 El Paso, Residential Single-Family Water Consumption Per Household
ELWPRS = f (ELYP/ELPPOP/PDCCE, ELWRATE/PDCCE, ELWRAIN, ELWDV)
Non-linear Least Squares
Annual data for 15 periods from 1985 to 1999

elwprs=	532.623*	elyp/elppop/ pdcce -	4263.63*	elwrate/ pdcce -	1.30863*
	(2.95100)		(5.99705)		(3.86451)
elwrain -	13.6829*	elwdv +	175.179		
	(5.83605)		(6.89316)		
Sum Sq.	41.8826	Std Err.	2.1572	LHS Mean	158.653
R Sq.	0.9689	R Bar Sq	0.9551	F 4, 10	70.1838
D.W.(1)	2.1113	D.W.(2)	2.6734		

Table 2 ***(contd).*** Border Model Water Equation Listings and Empirical Estimation Results

EQUATION 13 El Paso, Residential Multi-Family Water Consumption Per Customer
ELWPRM = f (ELWPRM.1, ELYP/ELPPOP/PDCCE, ELWRATE/ PDCCE, ELWRAIN, ELWHEAT, ELWDV)
Non-linear Least Squares
Annual data for 23 periods from 1977 to 1999

elwprm =	1.07733*	elwprm[-1]+	16.8698*	elyp/elppop/ pdcce -	19113.1*
	(16.4815)		(3.35880)		(2.52561)
elwrate/ pdcce -	1.97254*	elwrain -	2.02911*	elwheat -	52.2983*
	(1.82219)		(4.10477)		(2.78315)
elwdv +	236.919				
	(2.58434)				
Sum Sq.	8334.81	Std Err.	24.3997	LHS Mean	687.589
R Sq.	0.9675	R Bar Sq.	0.9512	F 7, 15	59.4446
D.W.(1)	2.1822	D.W.(2)	2.5061	H	-0.6860
AR_0 =	-0.57593*AR_1				
	(2.35887)				

EQUATION 14 El Paso, Commercial & Industrial Water Consumption Per Customer
ELWPCI = f(ELWPCI.1, ELWRATE/PDIGDP, ELWHEAT)
Non-linear Least Squares
Annual data for 15 periods from 1985 to 1999

elwpci =	0.88727*	elwpci[-1] -	30133.4*	elwrate/ pdigdp+	1.57934*
	(6.27343)		(2.40963)		(1.90854)
elwheat +	419.117				
	(1.74761)				
Sum Sq.	42315.5	Std Err.	62.0231	LHS Mean	851.893
R Sq.	0.8555	R Bar Sq.	0.8160	F 3, 11	21.6995
D.W.(1)	1.6282	D.W.(2)	2.0797	H	0.7250

Table 2 *(contd)***.** Border Model Water Equation Listings and Empirical Estimation Results

EQUATION 15 El Paso, Not Elsewhere Classified Water Consumption Per Customer
ELWPNEC = f (ELWPNEC.1)
Non-linear Least Squares
Annual data for 14 periods from 1986 to 1999

elwpnec =	0.82522*	elwpnec[-1] +	105.057
	(8.82793)		(0.49167)

Sum Sq.	2056515	Std Err.	413.976	LHS Mean	1727.03
R Sq.	0.8677	R Bar Sq.	0.8567	F 1, 12	78.7289
D.W.(1)	2.3938	D.W.(2)	2.0044	H	-0.8393

EQUATION 16 Ciudad Juárez, Total Water Meter Connections
CJWMTR = f (CJWMTR.1)
Non-linear Least Squares
Annual data for 40 periods from 1959 to 1998

cjwmtr =	1.04486*	cjwmtr[-1] +	1.53576
	(169.660)		(2.28225)

Sum Sq.	232.044	Std Err.	2.4711	LHS Mean	94.4862
R Sq.	0.9987	R Bar Sq.	0.9986	F 1, 38	28784.6
D.W.(1)	1.6020	D.W.(2)	1.9769	H	1.2290

EQUATION 17 Ciudad Juárez, Total Water Consumption
CJWTR = f (CJWTR.1)
Non-linear Least Squares
Annual data for 32 periods from 1967 to 1998

cjwtr =	1.00636*	cjwmtr[-1] +	3.40596
	(56.2671)		(2.18270)

Sum Sq.	209.832	Std Err.	2.6898	LHS Mean	82.1034
R Sq.	0.9958	R Bar Sq.	0.9955	F 2, 29	3406.62
D.W.(1)	2.2519	D.W.(2)	2.2821	H	-0.9410

MA_0 =	0.52572*MA_1
	(3.29705)

Prior to 1990, nominal water rates were not raised very frequently in El Paso (Archuleta, 1998). In subsequent years, political pressures have played central roles in rate adjustment efforts. To specify an equation for the average nominal water rate proxy is not, therefore, a matter of applying a standard theoretical commodity price model with well-defined supply and demand interactions. To reflect the fact that El Paso Water Utilities, the municipal water authority operated by the city, attempts to at least avoid real price erosion, Equation 11 utilizes one-year lags of the left-hand side variable and the United States gross domestic product (GDP) implicit price deflator as its only regressors. While this approach makes sense for periods when inflation adjusted water rates are fairly stationary, it remains to be seen whether its out-of-sample simulation properties are reliable in an era when more frequent rate hikes are expected (Jauregui, 1999). The empirical output associated with Equation 11 indicates that this approach provides a fairly good characterization of average water rates in the City of El Paso for the years between 1977 and 1999. It is possible that this basic specification may also prove helpful in modelling the pricing mechanism in other regions and municipalities where political concerns affect rate changes.

As in many urban economies, single-family residential water consumption accounts for the greatest percentage of water usage inside the El Paso city limits (Fullerton, 2000). Equation 12 models single-family per customer water consumption as a function of real per capita income, the proxy measure for price adjusted for inflation, annual precipitation, and a dummy variable for more restrictive watering regulations adopted in 1990. After adjusting for the number of regressors, the model explains more than 94 percent of the variation in the dependent variable. All of the coefficient t-statistics are significant at the 5-percent level. Similar to Pint (1999), rainfall plays an important role in determining single-family residential water consumption, but the temperature variable does not contribute in a statistically significant to this equation in the manner it does in the California study. Parameter instability causes the sample to be limited to a relatively short estimation period, 1985-1999.

Price and income elasticities are reported in Table 3. The single-family residential price elasticity is similar in magnitude to estimates reported in earlier research that fall within the inelastic range (Camp, 1978; Agthe and Billings, 1980; Billings, 1982; Weber, 1989; Michelsen, McGuckin, and Stumpf, 1998). The single-family income elasticity estimate is also numerically close to those obtained in some earlier empirical efforts (Gottlieb, 1963; Howe and Linaweaver, 1967), while higher than others (Camp, 1978), and lower than some (Agthe and Billings, 1980). Because much of the earlier research in this area has focused on price effects, additional investigation with respect to income effects on water consumption patterns would be helpful. The estimation results also imply that per household single-family water consumption falls by 1,740 gallons for every additional inch of rain per year in El Paso. With the respect to the dummy variable coefficient, non-price regulatory restrictions are calculated to have lowered annual single-family usage by nearly 11,800 gallons per household.

Table 3. Border Model Water Price and Income Elasticities

Consumption Model	Price Elasticities		Income Elasticities	
	Short-Run	**Long-Run**	**Short-Run**	**Long-Run**
Single-Family Residential	-0.430		0.473	
Multi-Family Residential	-0.445	NC	1.136	NC
Commercial & Industrial	-0.731	-7.902		

Multi-family residential water demand is the next largest category in El Paso. Many of the customers in this user class are apartment complexes that include fixed monthly water and waste water charges as part of individual lease agreements that are subject to change only at contractually specified points in time. Given this, a lagged adjustment specification is employed in Equation 13. Many of the summary statistics associated with this model are encouraging. Several surprises also appear in the results which merit additional attention. While most of the slope coefficient computed t-statistics are significant at the 5-percent level, the parameter for the number of days with temperatures greater than 90 degrees unexpectedly has a negative algebraic sign. Separately, the implied short-run income elasticity of this equation is greater than one. Previous research (Whitcomb, Yingling, and Winer, 1993) for multi-family water consumption indicates much lower sensitivity to price changes than what is shown in Table 3.

More surprising is that the regression coefficient estimated for the lagged dependent variable is greater than unity. That result implies that the speed-of-adjustment parameter for this equation is negative and overshooting behavior is present in this segment of the municipal water market. It also implies that the long-run price elasticity for this equation will carry a positive sign and the long-run income elasticity is less than zero. A variety of factors may have contributed to this result. Numerous complexes experimented with different billing approaches during the estimation period in question. Also, historically low income levels, plus the relatively flat overall rate structure in place through the 1980s in El Paso may have led to temporary behavior shocks in reaction to price changes over the course of the sample time frame. Whether parameter heterogeneity emerges in favor of an adjustment parameter that does not imply customer over-compensation as El Paso moves into a period of greater rate increases remains to be seen. At a minimum, the multi-residential water regression coefficient magnitudes shown in Table 2 call for careful monitoring of the model’s out-of-sample simulation output.

Because production techniques and input requirements generally undergo change in a deliberate manner that requires substantial planning effort, a partial adjustment specification is also utilized in Equation 14 for commercial and industrial water demand. Fewer independent variables are included in this model than in either of its residential counterparts. While the inflation adjusted price measure has the hypothesized negative sign and satisfies the 5-percent criterion, real income, annual rainfall, and the dummy variable for watering restrictions do not enter the final specification. Annual days with temperatures in excess of 90 degrees carries a positive coefficient, but the t-statistic falls below the 5-percent type-I error acceptance level.

Given that sales volumes for many companies are not directly tied to local economic performance, it is difficult to devise an accurate income measure for this aggregate business consumption category. Similarly, recent structural changes in the Greater El Paso metropolitan economy (Fullerton, 2000) may also pose obstacles to modelling per customer commercial and industrial water usage. While omitted regressor specification error cannot be ruled out, serial correlation correction is not required for Equation 14. As expected, the business sector short-run price elasticity reported in Table 3 falls within the inelastic range. The long-run elasticity measure indicates a high degree of commercial and industrial sensitivity to price changes. The latter calculation is probably affected by the closures of several water intensive apparel finishing companies that coincided with the recent historical period when rates were adjusted upwards more frequently. Due to this possible temporary channel of influence, out-of-sample simulation output from this model should likely be interpreted with caution.

All other water consumption per customer on the north side of borderplex is modelled within a single aggregate category. Included are municipal, county, state, and federal government agencies with operations in El Paso. Also included are private schools, public schools, and numerous non-profit organizations. Possibly due to the large variety of customer classes covered, none of the independent variables mentioned above proved helpful in modelling this catch-all classification. Equation 15, therefore, relies upon a simple autoregressive specification. In spite of its simplicity, residuals generated with this model are random in nature and do require any autocorrelation correction procedure to address unexplained systematic movements in the left-hand side variable.

Equations 16 and 17 are estimated for aggregate hook-ups and water consumption on the south side of the borderplex. At present, the Ciudad Juárez regression models rely on autoregressive specifications. Given the importance of reliable water supplies in developing economies (Merrick, 1985), it is encouraging that both sets of results carry with them statistically strong results. The latter provide at least partial evidence that the design of similar equations for planning efforts in other regions will potentially meet with empirical success. This segment of the overall model is still in its infancy. Collaborative data collection efforts are under way to expand the data set to include user-class breakdowns and price series. Eventually, this water demand sub-sector is expected to resemble more closely what is already in place for the north side of the border.

Because of the questions raised in reference to the econometric characteristics associated with Equations 13, 14, and 15, additional testing for other regional markets would be useful. Experimentation with other techniques and methodologies should also be considered for water consumption categories that exhibit statistical traits such as those discussed above. Some success has been obtained in other studies of industrial and agricultural water demand. At least two of these efforts have relied upon input/output water use coefficient approaches (Anselin, Rey, and Deichman, 1990; Michelsen, Taylor, and Taylor, 1998) and offer potential candidates for multiple user classes in subsequent research efforts. Given the successful results associated with the regression output for water meter connections, adoption of per capita usage identities that incorporate input/output matrix information probably represents a viable means for overcoming at least a subset of the problems identified above.

While the descriptive insights with respect to the statistical characteristics associated with the water block of equations in the borderplex model are useful, equally important are its out-of-sample simulation properties. Small sample size prevents engaging in simulation experiments that follow the generally accepted guidelines proposed by West (1995) and Granger (1996). The water equations have, however, been utilized to generate forecasts as part of the annual short-term business trend analyses conducted to assess economic conditions in the borderplex (Fullerton, 2000). Those results indicate that the total number of water customers in El Paso is likely to grow by roughly 1.7 percent per year and surpass the 165 thousand mark in 2002. Per customer consumption is projected to decline marginally during the out-of-sample simulation period, causing total municipal water consumption to climb to just over 42.5 billion gallons by 2002.

For Ciudad Juárez, municipal water consumption is forecast to grow more quickly. Total hook-ups extrapolate at a rate of approximately 5 percent per year and should reach almost 282 thousand by 2002. Population on the Mexican side of the borderplex is almost 77 percent larger than what it is immediately north of the Rio Grande River, but water hook-ups are only 54 percent higher (Fullerton, 2000). Given that, plus strong income growth, sustained rapid expansion of the Ciudad Juárez water grid is likely. Per capita usage is declining in Ciudad Juárez, but total water consumption should still trend upwards by more than 2.5 percent per year and surpass 163 million cubic meters by 2002. As noted above, additional data collection and disaggregation efforts are underway. If the latter are successful, elasticity and customer class statistical analysis for this geographic segment of the border will become feasible. Whether the current, and subsequent, published forecasts are accurate is an important question that cannot yet be addressed, but merits ongoing empirical scrutiny.

Readers will note that the information presented above considers only demand side issues. A more complete modelling effort would, of course, also include a treatment of the supply side. There have, in fact, been a variety of studies conducted with respect to water availability along the border (Eaton and Hurlbut, 1992). Time series data regarding water supplies at regional and municipal levels are typically difficult to obtain. In cases where such information is available, a potentially helpful empirical strategy to consider implementing is offered by microeconomic production theory. Namely, a cost function dual of the production function can be used to generate, under the assumption of cost minimization by system operators, derived output supply functions that are linear in the parameters (Huffman and Evenson, 1989). For non-public water systems, profit function duals can also be utilized to generate the underlying supply function specifications.

For the City of El Paso, and for Ciudad Juárez, the cost minimization approach is the logical methodology to adopt since both municipal water service providers are government agencies. At present, the various cost of production time series data needed to estimate the two supply functions are not available. Given that constraint, the supply side of the borderplex water market is not included in the current version of the forecasting system of equations. In essence, this represents an implicit assumption that the water supply functions in both cities are perfectly inelastic with respect to output prices. As input price data become available for this region, it may be possible to address questions surrounding the provision of water in a more satisfactory manner. Even in the absence of time series cost of production data, it is still anticipated, however, that demand-oriented efforts such as the one discussed herein represent a useful means by which analysts can meaningfully contribute to the ongoing debates regarding regional water consumption trends.

5. CONCLUSION

Water consumption trends are receiving increased attention in many regions throughout the world. To accurately gauge the severity of potential supply constraints and/or infrastructure costs requires quantitative assessment of aggregate consumption patterns. Regional econometric modelling and forecasting analysis offers a potentially useful means by which this objective may be attained. Doing so requires partially expanding the traditional modelling framework to include water meter and per customer consumption trends by rate class.

One such attempt is presented for the El Paso, Texas – Ciudad Juárez, Chihuahua borderplex, an international metropolitan area with approximately 2 million inhabitants situated on the international boundary separating the United States and Mexico. Empirical results are presented that indicate that regional econometric model coverage can be expanded to include water consumption in a relatively effective manner. For El Paso, statistical diagnostics for all four categories of meter connections and for the average rate variable seem reasonable. With respect to per customer usage equations, single-family output matches well with previously published analyses. Multi-residential, business, and not-elsewhere-classified per customer demand equation results are less encouraging. Alternative methodologies such as the input/output approaches employed elsewhere should potentially be considered when analysing these user classes in subsequent analyses. While detailed time series data for the southern geographic component of the borderplex are not yet available, variations in the aggregate water data are found to be systematic enough to analyse via autoregressive equation specifications.

In spite of the possible shortcomings associated with estimates discussed in this paper, partial modification of the traditional regional econometric modelling framework to include regional aggregate water usage appears feasible. The overall usefulness of such efforts is ultimately an empirical issue that can easily be assessed. Such assessment will require monitoring the various user-class forecasts generated with the borderplex model each year plus extra-regional confirmation via development of similar estimation efforts for other water markets. With only three published forecasts to date, it is not yet possible to formally assess *ex ante* border model water simulation performance. Careful monitoring of overall accuracy can, however, minimize the risk of systematic over-prediction or under-prediction for individual user categories. This initial research for El Paso and Ciudad Juárez offers a potential blueprint for other regions and suggests a means by which policy analysts can study aggregate water consumption behaviour.

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