An Empirical Study of Factors Affecting Water Loss in Mexican Cities

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ABSTRACT

Water losses are a major problem for water utilities, as they affect the environmental and financial sustainability of urban water services. The aim of this paper is to identify the factors related to water losses in Mexican urban water utilities by means of regression analysis including variables related to operation costs, staff, water prices, consumption, climate, as well as demographic and socio-economic aspects of 73 urban localities. Results show that water losses are negatively and significantly associated to production costs, per capita consumption, persons per connection, and population. Water losses are positively and significantly associated to the number of staff per customer in a utility. Results are not conclusive on the effect of private management on water losses.

Keywords: Water losses; physical efficiency; urban water utilities; Mexican utilities; water management

1. INTRODUCTION

Urban water in Mexico has become an issue of major concern because of the increasing demand of water and sanitation services related to population growth and the rapid urbanization of Mexico during the last decades (Aboites, 2009). In 1930 urban population was only 33% of the total; in 2010 it increased to 78%. Today approximately 87 million people live in urban localities (National Institute of Geography and Statistics, INEGI, 2010), and it is projected that Mexican population will reach more than 121 million people by 2050 (National Population Council, CONAPO, 2006), and most of them will be living in even more concentrated and complex metropolis.

Thus, water utilities in Mexico face the challenge of providing water to an increasing population, especially in the arid lands in the north of the country (Pineda and Salazar, 2010). However, despite of the population growth and ever scarcer water resources, almost half of the water produced in Mexican cities is lost in the networks, mainly due to leakages. As cities grow, water becomes scarcer and more costly to produce because it has to be transported from further locations or pumped from deeper water tables. Water loss reduction is more cost effective than to develop new water sources, which not only requires large amounts of financial resources, but also poses high costs and threats for the environment. Water losses imply other problems such as financial insolvency of utilities, health risks due to contamination of water through leaks, and environmental deterioration due to the overexploitation of water resources. This problem is not exclusive of Mexico, since many cities around the world are now facing water scarcity at levels that impact the quality of life of its inhabitants, and the high rate of urbanization in developing countries suggest that water losses reduction will become an important challenge for the cities around the world in the near future.

Therefore, it is important to study the factors that affect water losses, in order to provide insights for better management of water

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resources and conservation of water in distribution networks. This paper focuses on the evaluation of factors that affect water losses in Mexican localities in order to achieve a better understanding of this problem in this and other countries with similar problems and characteristics. Benefits derived from this knowledge are related to savings in energy and water, better water quality, and more availability of this resource without affecting other sources and the ecosystems depending on them. The first section of the article explores the antecedents of urban water administration and historical indicators of water losses in Mexico. In the second section the antecedents of research on water losses are reviewed. In the third section the modeling framework is specified, and in the fourth section results are presented. Finally conclusions derived from this research are presented.

2. WATER MANAGEMENT IN MEXICO

During the last 60 years the water administration sector in Mexico has gone through a series of institutional reforms to decentralize water services from the federal level to the municipalities (Pineda and Salazar, 2008; Rodriguez, 2004). In this process, one of the most important events was the creation of the National Water Commission (CONAGUA) in 1989, which is the federal agency in charge of the administration of water resources in Mexico. The creation of this entity was supposed to address the major problems in local water systems at the time: 1) lack of technical capacity, 2) highly politicized administration, and 3) shortage of financial resources due to unpaid rates (Olivares, 2008). Despite these actions, water sector is still highly concentrated and local management depends on central decisions related to funding to administer water in cities (González, 2000).

In 1992 the National Water Law was enacted including two instruments: first, an institutional frame for water rights embodied in the Public Registry of Water Rights (REPDA for its acronym in Spanish); and second, the permission for private participation in building and operation of drinking water and sanitation systems (Collado, 2008). Nevertheless today urban water in Mexico is provided mainly by local government owned utilities, and there are only three utilities managed by private investors (Saltillo in the northern state of Coahuila, Cancuninthe southeast, and Aguascalientes in central Mexico).

According to Tortajada (2000), Mexico has reached some important goals in supplying urban water and sanitation services. Up to 2009, 91% of Mexican population had water services in their dwellings, while 87% had sewage services. These amounted to almost 94 and 90 million people respectively (CONAGUA, 2010a). Coverage percentages in Mexico are higher than in other large Latin American countries. For example Brazil has 81% of total water coverage, and 43% of sewerage coverage (Sistema Nacional de Informaçõessobre Saneamento, 2008; The International Benchmarking Network for Water and Sanitation Utilities, Ibnet, 2011); Argentina had 85% and 63% respectively in 2006 (Ibnet, 2011); and Venezuela had 90% water coverage and 74% sewage coverage also in 2006 (ibid). Nonetheless there are also good Latin American examples such as Chile with almost 100% of water and sewerage coverage (Ibnet, 2011; Superintendence of Sanitary Services, 2010). Finally, Mexico has a fair service coverage compared to some developed countries such as Belgium, Canada, Denmark, Germany, and the United States of America (100% in both indicators) (World Health Organization and UNICEF, 2006).

Regardless of these simple gauges, problems that were identified more than 20 years ago are still present in Mexican cities, in addi-

tion to new conditions that weaken the already poor management of utilities (Aboites et al., 2008). Among these deficiencies, those related to water losses in urban utilities are central. One of the most used concepts for referring to water losses is "unaccounted for water" (UFW), which is a measure of the operational proficiency of a water system and regularly includes losses from the physical distribution and storage systems, illegal connections and thefts, as well as public uses that are not measured and do not produce revenue (Wallace, 1987). The International Water Association (IWA) recommends the use of the concept of "Non-revenue water" (NRW) as a better approach (Lambert, 2002).

In Mexico, CONAGUA measures and reports "physical efficiency" of utilities as a parallel concept of NRW, and it refers to the ratio of billed volume with respect to supplied volume of water (CONAGUA, 2009a). IWA suggests to disaggregate and measure independently the components of NRW, and to calculate real losses taking into account the number of connections, extension of water network, average operating pressure, and location of meters (Lambert, 2002). However this kind of information is difficult or even

impossible to obtain for most cities in Mexico, and accordingly in this paper the term "water losses" will be used to indicate NRW, or the general measurement of the amount of water that is not accounted for (the "unbilled volume" in Figure 1).

During the last 15 years water losses in Mexican urban utilities have been around 45% and remained at the same levels since they were first measured by CONAGUA (2010b), as seen in Figure 2. Water losses are high in comparison to developed countries; while in Mexico it rounds 45%, in the United States it ranges from 5 to 37%, in Finland from 12 to 25%, and in Denmark it equals 7.6% (Lambert, 2002).

It is also estimated that in Mexico most NRW is due to leaks, but there is no reliable way to measure these volumes as there is no full metering over the distribution systems. Total elimination of water losses by leaks is impossible, but reductions can be done up to the economic level of leakage, which is the point "at which it would cost more to reduce leakage further than to produce the water from another source" (OFWAT, 2008). According to Ochoa and Bourguett (2001), the economic viable goal for Mexico is up to 20% of losses.
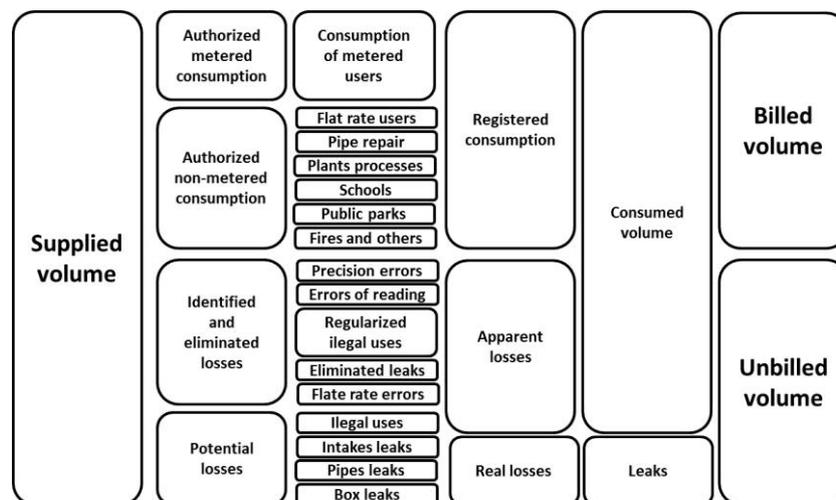

Figure 1 Standard structure of water balance. Translated from CONAGUA, (2009a)
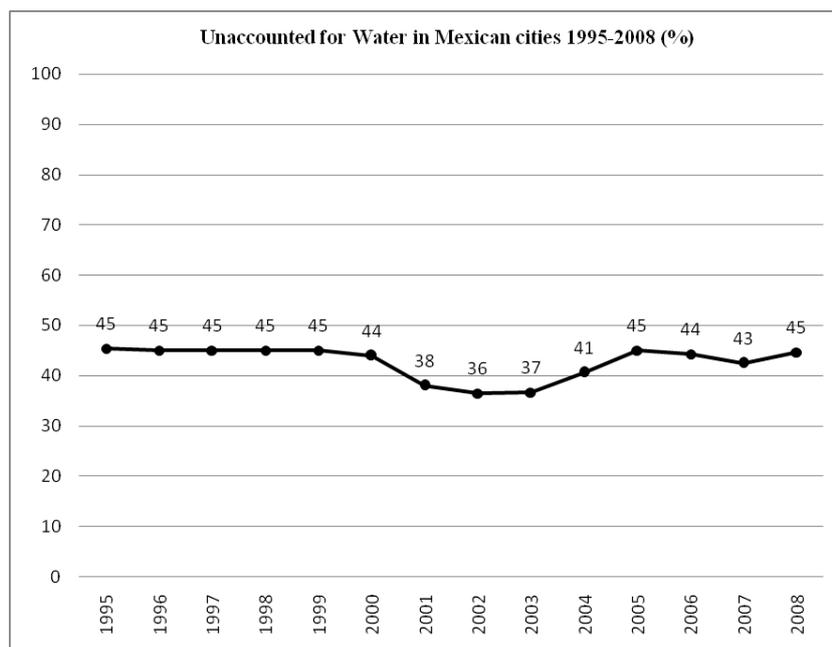
Figure 2 Unaccounted for Water in Mexican cities 1995- 2008. CONAGUA, (2010b)

3. EMPIRICAL FRAMEWORK

Research on the determinants of water loss is scarce, there are very few published studies on the factors that affect water loses in Mexico (IMTA, 2001; World Bank, 2005). Most research on urban water in Mexico has focused on other problems related to the general functioning of water utilities rather than to specific aspects of water losses. These reports regularly use only small samples of cities or unique cases with a few indicators in a descriptive fashion. More recent studies have used bivariate analysis to study correlations between performance of utilities and some characteristics of cities; for instance, the reports of the Water Advisory Council of Mexico (CCA), which benchmarked the performance of 24 large utilities in 2010, and 50 in 2011 (CCA, 2010, 2011).

Park (2006) argues that there is no comprehensive theory to explain water losses, and that it is more common to find practical guidelines to manage water loss than research on its determinants. Nevertheless, there are independent empirical studies that approach this issue by means of analyzing the effects of different kinds of variables on water physical management. González-Gómez and García-Rubio (2008) explain that some factors affecting management cannot be controlled by utility managers, for example: the density of products or customers, the origin of hydric resources (superficial or underground), the orography and urbanization patterns, the seasonality of demand, and climatic variables. In many cities of Mexico water production is too costly due to this kind of variables: it has to be pumped several meters to the surface (especially in northern and central cities that depend on aquifers), transported through (sometimes hundreds) of kilometers, treated to make it safe for household use, and distributed through large pipe networks. In addition to the running costs of these procedures, the investments required for infrastructure are significantly high.

Some of the uncontrollable factors for managers in relation to water losses are included in this research: temperature, precipitation, population size, and GDP. Variables of temperature and precipitation provide an approx-

imate indicator of water availability in a region; higher levels of precipitation would be associated to a lesser pressure to reduce water losses (if water is abundant, it could be less costly to produce it for public and domestic consumption), while lower levels of precipitation represent a pressure for decreasing water losses, due to continuous water shortage and the possibility of recovering big volumes of non-revenue water (Park, 2006). In addition to the evident effect of higher temperatures on water consumption, extreme weather conditions can also affect the pipelines, producing leaks that are the main reason for water losses in distribution networks (ibid).

The characteristics of the population also play an important role. Growing populations increase the total demand for water within a city, put more pressure on water availability, create a need for more water in the system, and thus increase the marginal cost of the water (the incremental cost of one more unit produced), which finally is thought to increase the pressure for water loss reduction. On the other hand, some scholars have found a positive relationship between the size of population served and the level of water losses considered as a percentage of total supply, especially when there is an expansion in service density (Park, 2006). In this paper the density of services is measured as people per connection, which is expected to correlate positively with water losses; however the influence of the network size (represented by population size or density of services) on water loss would finally depend on the distribution of connections and specific characteristics of the network (Alegre et al., 2006), so its net effects are unclear and should be referred to the specific situation of cities.

GDP has similar effects on water demand as does an increasing population, because expanding economies regularly raise the demand for water due to growth of economic activities and the additional household income. In both cases, water loss prevention would provide the additional water required, so it is expected that water loss correlates negatively with income. GDP is also an indicator of the amount of potential resources that could have a utility to face the challenges of repairing pipes and expanding capacities of services, therefore this would make possible to decrease water losses. In Mexico, it has been found that general performance of urban utilities is positively correlated to GDP per capita (0.31) (CCA, 2011), but this statistical relation is inconsistent in some localities, and particular analyses of water loss are not available.

The cost of water production and per capita consumption are located in the middle of the controllable-uncontrollable factors spectrum. The first variable has some components out of control for managers such as the cost of chemicals and energy for water production, but the size of staff and some operational aspects that affect total costs can still be managed. In a scenario of scarcity, water losses are also financial losses for utilities, so it would be desirable to reduce them as much as possible, as long as the cost of the water lost is greater than the cost of avoiding losses. It is expected that utilities with higher production costs favor water conservation and look for more efficient use of resources (Agthe and Billings, 2003).

Various determinants of per capita consumption are perceived too. There is a minimum amount of water necessary for daily household uses and sanitation (relatively uncontrollable for managers), but there is also a gap in consumption that depends on the price of water, income, and discretional uses of consumers that can be altered by means of policy instruments, both pecuniary (such as pricing) and non-pecuniary (such as rationing or mandating the installation of water saving devices). There is no evidence that clearly specifies whether water losses are positively or negatively correlated to per capita con-

sumption, but this can be considered a proxy for demand and, as stated by Park (2006), water demand in general terms is negatively related to water losses.

There are also a number of variables that actually affect efficiency related to water losses, and that can be modified trough policy actions. Factors in this study include: price, nature of ownership (public or private), staff of utilities, and coverage of metering. Price structures can in fact encourage conservation (Corral et al., 1999), but this can be truth not only on the customer side, but also on the side of utilities. Scholars have found that water is usually not priced according to its real cost in terms of production and environmental effects. Were water priced at its marginal cost, conservation efforts on the side of customers and utilities would be enhanced (Agthe et al., 2003). Park (2006) argues that local governments would face opposition to price increases when high water losses are present, so it is likely that the amount of water losses decrease when prices increase or at least are intended to increase.

The nature of the ownership of utilities is also thought to affect losses. Private utilities would be more prone towards water loss reduction because publicly owned utilities are easily affected by political pressure, thus it is harder to carry out management practices that enhance efficiency. Also public utilities are more likely to have financial deficits that are financed by the taxpayers. However there is no definitive evidence which indicates a causal relation between management ownership and efficiency, so there could be other factors which explain these differences (Anwandter and Ozuna, 2002); for example the institutional or regulatory framework that is applied to private, but not to public utilities (González-Gomez and García-Rubio, 2008), as well as the fact that private companies regularly take over contracts which they estimate more profitable, so there can be some pre-

vious advantages for privately managed utilities in comparison to government managed organizations (ibid).

Finally, number of staff and metering are expected to relate negatively to water loss. Number of staff indicates the amount of human resources devoted to management of water, and indirectly the number of people that could be in charge of leakage detection and repair. In this case the variable is used to indicate the labor costs of repairing leaks. With respect to metering, it has been found that the variable has a significant effect on water conservation especially for identifying apparent losses, as metering permits locating more precisely where the consumptions are and how much volume is used (Agthe and Billings, 2003). All these variables were included in the regression analysis described in the next section.

4. METHODS AND PROCEDURES

4.1 Modeling framework

In order to estimate the effect of several variables on water loss in Mexican utilities, a regression analysis was carried out. The empirical model was:

$$
\begin{aligned}
WaterLoss_{it} = & \beta_0 + \beta_1 \ln(COST_{it}) + \beta_2 \ln(PRICE_{it}) \\
& + \beta_3 \ln(CONS_{it}) + \beta_4 \ln(STAFF_{it}) \\
& + \beta_5 PRIVATE_{it} + \beta_6 \ln(POP_{it}) + \beta_7 \ln(PPC_{it}) \\
& + \beta_8 \ln(GDP_{it}) + \beta_9 \ln(TEMP_{it}) \\
& + \beta_{10} \ln(RAIN_{it}) + \beta_{11} MEASURE + \varepsilon_{it}
\end{aligned}
$$

Where $COST_{it}$ is the average production cost per cubic meter for the i-th utility in the year t; PRICE is the average price charged per cubic meter; CONS is the per capita consumption measured in liters per day per person; STAFF is the number of staff per every thousand connections; PRIVATE is a dummy variable that indicates that the utility is managed by a private investor; POP is the population of the city where the utility is located; PPC indicates the number of persons per connection;

GDP is the per capita municipal gross domestic product; TEMP is the historical average temperature in Celsius degrees; RAIN is the average annual precipitation in mm; MEASURE is the coverage of metering in particular connections. All β's are fitting constants and ε is the error term. Pooled OLS and panel data models (fixed and random effects) were runin order to estimate the effect of each of these variables and check whether they are robust to model specification and estimation procedures. Compared to pooled OLS, panel data models provide more efficient estimates in the presence of autocorrelation and reduce identification problems (Verbeek, 2008). The statistical package Stata 9.0 was used to fit these models.

4.2 Data

Data on 73 water utilities were obtained from the yearbook publications of CONAGUA for the period 2005-2009 (CONAGUA 2006, 2007, 2008, 2009b and 2010b). However, not all utilities have data for the whole period, so the data have an unbalanced panel structure with an average of 2.3 observations per utility. Population and municipal GDP per capita were obtained from the National Council of Population (CONAPO, 2001). GDP per capita was only available for year 2000 and thus remains invariant across time. Historical average precipitation and temperature data was obtained from the Mexican Institute of Water Technology (IMTA, 2007), and is invariant across time as well. Summary statistics are shown in Table 1.

Table 1 Summary statistics of variables

Variable	Units	N	Mean	Std. Deviation	Min	Max
Water Loss	%	156	46.6	13.4	7.6	84.8
COST	Constant (2009) Pesos	156	5.1	2.63	.68	18.5
PRICE	Constant (2009) Pesos	156	5.8	2.93	1.56	16.9
CONS	(liters/person/day)	156	72.8	29.45	14.94	222.6
STAFF	Staff per thousand connections	156	5.2	1.93	2.01	16.6
POP	Inhabitants	156	277,023	294,553	18,550	1,497,499
PPC	Persons per connection	156	3.3	.995	1.29	7.6
GDP	Constant (2009) Pesos	156	110,554	37,980	42,681	222,468
TEMP	Degrees Celsius (historic average)	156	22.2	3.4	13.9	27.67
RAIN	mm per year (historic average)	156	684.5	492.32	31.9	3,041.8
MEASURE	% of connections measured	124	57.9	31.3	.64	100

Table 2 Regression Estimates of Models

	(1) Pooled OLS	(2) Pooled OLS	(3) Pooled OLS with Clustered S.E.	(4) Random Effects	(5) Fixed Effects
ln(COST)	-19.472***	-21.761***	-21.761***	-18.637***	-14.743***
	(2.374)	(2.079)	(2.957)	(2.021)	(2.587)
ln(PRICE)	6.374***	6.331**	6.331**	.645	-10.704***
	(2.237)	(1.857)	(2.565)	(2.187)	(3.743)
ln(CONS)	-24.179***	-25.081***	-25.081***	-33.127***	-53.971***
	(3.500)	(3.088)	(3.998)	(3.34)	(5.616)
ln(STAFF)	7.848**	10.403***	10.403***	14.949***	11.817**
	(3.915)	(2.820)	(2.700)	(3.443)	(5.468)
ln(POP)	1.901	2.058*	2.058	2.103	-27.853**
	(1.265)	(1.069)	(1.662)	(1.536)	(14.788)
ln(PPC)	-25.265***	-25.628***	-25.628***	-31.325***	-24.051***
	(4.530)	(3.858)	(3.796)	(4.185)	(7.205)
ln(GDP)	5.179	5.896**	5.896	5.617	
	(3.287)	(2.837)	(3.757)	(4.270)	
PRIVATE	-8.239	-7.490	-7.490**	-1.714	
	(5.106)	(4.656)	(3.504)	(6.668)	
ln(TEMP)	.3477633	.213	.213	.039	
	(.267)	(.224)	(.259)	(.341)	
ln(RAIN)	1.431586	.970	.970	-.601	
	(1.389)	(1.217)	(1.799)	(1.827)	
MEASURE	-.0446627				
	(.0305)				
N	124	156	156	156	156
Within R²				0.5855	0.6651
Between R²				0.6395	0.2970
Overall R²	0.6236	0.6228	0.6228	0.5814	0.2117
Adjusted R²	0.5866	0.5962			

Note: Standard errors in parenthesis. *, **, *** indicate significance at 10%, 5%, and 1% level.

5. RESULTS AND DISCUSSION

Table 2 summarizes the regression estimates for the five regression models run. Model 1 is a pooled OLS regression with all independent variables included. Model 2 is also a pooled OLS regression, but the MEASURE variable was dropped, which allowed an increase in the sample size from 124 to 156, as well as an increase in the number of utilities in the sample from 65 to 73.

In models 1 and 2, COST, PRICE, CONS, STAFF, PPC and GDP are significant. As ex-pected, COST has a negative sign which indicates that water losses are reduced in the presence of higher costs of production. On the other hand, the coefficient of the PRICE variable is positive, though it would be expected that higher prices would encourage water conservation. A similar result was obtained by Park (2006) who argued that utilities actually use price increases to offset financial losses caused by water leakages, therefore the sign is positive. CONS has a negative sign which indicates that higher per capita consumption is associated to a reduction of water losses.

STAFF has a positive sign, which indicates that a large staff relative to the number of connections increases the cost of reducing water losses.

Model 3 is an OLS regression with standard errors clustered around utilities. This provides a robust estimation of parameters in the presence of autocorrelation due to repeated measures on the same unit. In this model, COST, PRICE, CONS, STAFF and PPC are significant. PRIVATE is also significant and has a negative sign, which indicates that utilities with private management have around 7.5% less water losses compared to publicly owned utilities. TEMP, RAIN and MEASURE are not statistically significant in any of the Pooled OLS models.

Model 4 is a random effects model, where COST, CONS, STAFF and PPC are significant and have the same sign as in the pooled OLS models. PRICE has a positive sign, but it is not statistically significant in this model. Unlike in model 3, PRIVATE is not statistically significant in model 4. Model 5 is a fixed-effects model, which does not include time invariant variables. In this model PRICE is significant and has a negative sign, unlike all other models, which means that controlling for individual effects of utilities, the price of water encourages conservation as it was expected. COST, CONS, STAFF and PPC are also significant and have the same sign as in the other models. Models 4 to 5 were run also with the variable MEASURE included, but this variable remains non-significant in all models (the results are not shown in table 2).

Although many factors are usually said to affect water losses, these models show the importance of some specific variables. Variables COST, STAFF and CONS are significant and have the same sign in all models, so they are robust to model specification and estimation methods. As argued, an increase in costs would induce utilities to reduce water losses in order to reduce the overall cost of operation. The number of staff relative to the size of the network in a utility is also an important factor affecting water losses; it can be seen as a proxy for labor costs of maintenance and reparation of the network, thus the cost of reducing water losses will increase as these costs go up. Another factor that puts pressure on utilities for reducing water losses is consumption, because a greater demand would require the production of an additional quantity of water, and as it was previously stated, water loss reduction is usually more cost effective than developing new water sources.

Another variable that was significant in all models was the number of persons per connection (PPC), which has a negative sign that indicates that the greater the number of people per connection, the less water losses. This could be related to the fact that, as stated by Ochoa and Bourguett (2001), most water leaks are located in the connections of individual houses to the main network. Greater household sizes means that there are less connections relative to the size of the population, so it is less costly for water utilities to monitor a larger fraction of customers. Therefore, the structure of the population matters for water loss issues. According to the fixed effects model, population (POP) is significant and has a negative sign, which means that an increasing population puts additional pressure on utilities to reduce water losses and make a more efficient use of the available water sources. The fixed effects model also suggests that the average price of water (PRICE) is negatively associated to water losses, as it was expected.

The identification of these variables provides an important insight for understanding of water loss levels in Mexican utilities. Production costs are directly related to water losses because the more it costs to produce water, the greater impact water losses have on the finances of the utility, thus locations where water is scarcer and more costly are

more likely to reduce losses. When combined with high population growth and higher consumption levels associated to higher living standards, the pressure on utilities to reduce water losses increases. This could explain why the north of Mexico, being the most arid and fastest growing region in the country, is home to those utilities with the lowest water loss levels, such as Tijuana, Monterrey and Mexicali (Lutz and Salazar, 2011).

In order to improve management in utilities, one of the main issues to be addressed is that of staff and labor costs. According to Aguilar (2011), labor costs amount up to 57% of operational costs in some Mexican utilities, compared to 26% in neighboring American utilities just across the border. Thus, labor costs use up scarce resources that could be used for reducing water losses and provide the population with a better quality service.

A variable of interest for many researchers is the effect of ownership on the performance and efficiency of utilities. It has been argued that private utilities have greater incentives to reduce costs, thus they would be more likely to reduce water losses up to the point of economic level of leakage; however only in model 3 the variable PRIVATE is statistically significant. Thus the evidence that private ownership or management of utilities would enhance water conservation is not conclusive. This is in line with previous findings by Andwanter and Ozuna (2002) that private utilities are no more efficient than public ones. An issue that might be affecting these results is the fact that there are only four Mexican cities where private partners are directly managing the utility, all with different modes and degrees of private participation. Thus it would be relevant for the research in this area to analyze the cases of these utilities on an individual basis, with special attention to the terms of the contracts for operation of water services in these cities.

CONCLUSIONS

The analysis of factors that determine the level of water losses in Mexican cities indicates that utilities tend to reduce their water losses in the presence of higher average costs and larger consumptions. Also, a greater population induces water loss reductions due to a high demand for services. As population and consumption increase in the future, it would be expected that cities will face greater costs of production, and will look forward to reduce losses. Results also indicate that the number of staff per thousand connections correlates with water losses. This could indicate that a more efficient use of labor in utilities would be reflected on the reduction of water losses. Finally, results are not conclusive about private utilities having lower levels of water losses. In general terms, it is concluded that this analysis provides confirmatory evidence on some of the factors that the literature suggests as influential on water loss levels.

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