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# TARIFF STRUCTURES, WATER DEMAND AND ELASTICITY IN LA PAZ CITY, BOLIVIA

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Water demand regulation is commonly addressed using segmented tariff structures. In La Paz, Bolivia, access to water is a human right; therefore, monetization is a sensitive matter. The paper presents a brief evaluation of water tariff and water demand under an elasticity approach. Within the tariff scheme, a solidary tariff comprises an unusual segment, assigned to low-income users with less than 15 m3 of water consumption per month. An impact of such category was a reduction in water consumption of 21% between 2007 (the year when the rate was applied) and 2010. The econometric model adjusted for the same period shows the following: i) a negative relationship between the tariff and the water demand (i, e., a 10% increase in the rate implies a 3.3% decrease in water demand); ii) a positive relationship between total connections and total demand and; iii) a positive relationship between the total income of the water company and the total water demand. In addition to the econometric aspects, the complexity of user behavior would be based on much more complex aspects.

*Keywords: elasticity; policies; tariff*

# ESTRUCTURAS TARIFARÍAS, DEMANDA DE AGUA Y ELASTICIDAD EN LA CIUDAD DE LA PAZ, BOLIVIA

La regulación en el consumo de agua es usualmente abordada utilizando estructuras de tarifas segmentadas. El artículo presenta una evaluación breve del impacto de una categoría de tarifa denominada “tarifa solidaria” en la demanda de agua, bajo un enfoque de elasticidad, en La Paz, Bolivia. Aquella tarifa se asigna a usuarios domésticos de bajos ingresos, con menos de 15 m3 de consumo de agua por mes. Para evaluar el impacto de aquella en la demanda de agua, datos históricos muestran una reducción de 21% en el consumo entre los años 2007 (año en el que se aplica la nueva tarifa) y 2010. El modelo econométrico ajustado para el período muestra lo siguiente: i) una relación negativa entre la tarifa y la demanda de agua ( i, e., un aumento del 10% en la tasa implica una disminución del 3,3% en la demanda de agua); ii) una relación positiva entre conexiones totales y demanda total y; iii) una relación positiva entre el ingreso total de la compañía de agua y la demanda total de agua. Además de los aspectos econométricos, la complejidad del comportamiento del usuario se basaría en aspectos mucho más complejos.

*Palabras clave: elasticidad; políticas; tarifa*

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## 1. Introduction

Water is a fundamental resource worldwide. In the latter decades, commercial, residential and industrial users have generated considerable pressure on it, attracting the attention of scientists and practitioners. In Latin America, the management of water resources is commonly addressed from a sectorial perspective, mostly centrally planned, with deficiencies in the coordination processes. Planning and management of water resources usually react after a crisis has occurred, in attention to special interests, or from a political motivation (Indij, Donin and Leone, 2011).

The challenge of water management is to address the demand, utilizing a supply that is expected to fulfill it. From a historical perspective, it has been focused from the water supply perspective, due to the increasing importance of ecological, financial and political limitations. Later, the perspective has evolved, understanding that the problem of water management is not only due to inadequate supply, but also due to inadequately defined demand management strategies (Indij, Donin and Leone, 2011).

The promotion of the economic and social development of societies is linked to drinking water and sanitation. For that reason, literature suggests that a new vision is required, towards the formulation of efficient public policies. This new management approach must be carried out observing the current legal order, welcoming perspectives where natural ecosystems are integrated together with the human system, based on economic efficiency, ecological sustainability and social equity (Colmenárez and Salazar, 2016).

The increasing attention to the rational use of water resources, under the constant threat of climate change, ENSO (El Niño-Southern Oscillation) phenomena and population growth both in La Paz and in other cities in Bolivia, have attracted attention on the increasing possibility of an imbalance between water supply and water demand. The complex interaction between the factors involved in the management of water in a given geographic space requires taking into account both environmental and physical aspects (climatic and technological factors), as well as social and economic aspects (land and territory patterns), which turn the problematic into a multidimensional issue (Galán Ordax, del Olmo Martínez and López Paredes, 2004).

In general and in particular in Latin America, policy makers focus on water conservation through water demand control methods. Agencies and companies which provide this service use water pricing policies as an instrument to control water demand for household users. However, for the design and evaluation of a price policy, economic, social and political restrictions must be previously incorporated. The complexity of the problems related to water resources management demands contributions from different professional and technical visions, in order to provide meaningful and relevant policy formulations.

Under the described framework, and given that in La Paz, Bolivia, as in the rest of the country, there is a demand for better water services, in order to guarantee economic growth and social development, for the benefit of people, the present paper addresses the formulation of an econometric model, as a contribution in the process of water planning on the basis of economic factors. An econometric model is a mathematical formulation which contains the necessary specifications for its practical application. The purpose of such model is to provide mean to analyze relationships which link several variables, the relationships among them, effects or existing interdependencies; its formulation follows a set of sequential stages, which were addressed in this investigation.

### 1.1 Objectives

This paper examines the elasticity - price of water demand, in a residential sector of La Paz, an Andean city in Bolivia. The analysis addresses a particular period which highlights a policy defined under a complex socio-political context occurred during a political transition in the period 2005-2010. Among the policies evaluated it is the so-called “solidarity tariff”, suggested by water planners as an aid to low income users, but with unclear technical factors supporting it.

## 2. Study case and methods

### 2.1 Context of the study case

In the last decades, Bolivian issues related to water quality and quantity have increased due to factors such as urban growth, water pollution at sources and headwaters degradation. All together increase the possibility for disaster occurrence due to water scarcity at major cities. The most recent and critical case occurred in the period 2016-2017 when El Niño-Niña climatic anomalies, triggered a period of water scarcity affecting five out of nine regions in Bolivia. As a result, in year 2017 La Paz city has faced one of the most critical situations regarding water availability in the last decades, when an imbalance between water demand and water supply due to a dramatic reduction in water levels at the main reservoirs caused water shortages in the entire city.

The water scarcity event started the first months of the hydrologic year (coincident with the end of the dry winter season, in October), lasting to the first months of the rainy season of the next year (coincident with summer season, between December and January). During those months, universities, schools, hospitals and any other public facility in La Paz were affected, causing public protests and queues for water everywhere.

Given that no shortage due to climatic factors could occur from one day to another, as it happened during the 2017 water crisis in La Paz (water shortage was announced on the same day when tap water turned into a smelly brownish color fluid before the service stopped), it is likely that serious technical issues in the water management system led to the problems that people had to face then, as was suggested by researchers and engineers during meetings and public seminars organized after the crisis.

### 2.2 Description of the water supply system, water consumption trends and tariff structures

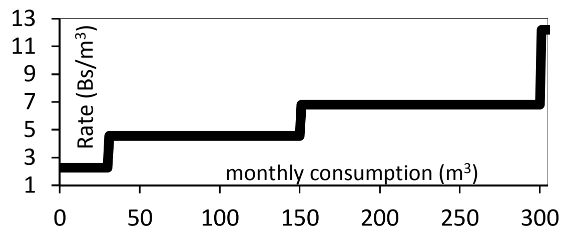
A public company (EPSAS) is in charge of the water system administration in La Paz (population near 1 million people) and the neighbor city of El Alto (population of 1 million people). There are three systems to address water supply needs in La Paz: Achachicala system, Pampahasi system and El Alto system. As part of El Alto system and with contributions to water supply to La Paz downtwn, the Milluni basin contributes an important volume of total water supply, with a capacity of 10,000,000 $m^3$ and a watershed area of 2,450,000 $m^2$ (Alvizuri 2019). Milluni constitutes a relevant part of the system as it is a basin that is polluted by mining activities (Raffailac 2002).

Regarding tariff structures as a water demand regulator, EPSAS started its operations by implementing a block rate system, with the objective of managing water demand by introducing an incentive which would motivate the user to remain in the lower blocks of the tariff stratum.

Starting 2007, EPSAS decided to implement a new category of users in relation to the domestic tariff, named "solidary tariff". The new category is aimed at reaching social sectors with less incomes than the average population; the tariff was also advertised at promoting an environmental-friendly policy towards water consumption. Such expectations is unlikely to respond to a technical reasons since we could not find any data to understand such a policy. The complex process to obtain data from EPSAS, a public company which is entitled by law to share their data with the public, appears to support such hypothesis. After all that, our motivation to write this paper rises.

The solidary tariff consists of a fee of 1.78 Bs/m$^3$ (about 0.23 euros per cubic meter) when water consumption is below 15 m$^3$/month. Bs stands for the Bolivian currency. The next categories charge a fee of about 0.64 Euro/m$^3$ for consumption rates lower than 150 m$^3$/month, about 0.90 Euro/m$^3$ for consumption rates lower than of 300 m$^3$/month, and about 1.54 Euro/m$^3$ for consumption rates higher than 300 m$^3$/month (figure 1).

**Figure 1: Block rate tariff in La Paz**




Water demand trends presented a response to the introduction of the solidary tariff, by a change in the behavior starting in 2007 (figure 2). Water consumption before the solidary tariff, from January, 2005 to June, 2007, showed a rather uniform consumption within a range of 1.8 MCM (million cubic meters) to 2.0 MCM, with an average of 1.9 MCM. From July 2007 to October 2010, data showed a change in the trend, initially due to implementation of the solidary tariff, which altered the usual water demand behavior. Water demand during such a period varied without a clear pattern, within a wider range from 1.8 MCM to 2.1 MCM (2.0 MCM, in average).

The impact of the solidary tariff on the average consumption per user is presented in figure 3. There it is shown that the average consumption per home user presents a decreasing trend by a rate of 46 m$^3$/month in year 2005, to 37 m$^3$/month for year 2010, which represents an average of 21% reduction in consumption. Thus, it is shown a change in the trend due to the application of the new block rate tariff structure; however, given the complexity of the responses of water users to such an external incentive, a more detailed evaluation is required to estimate the sensitivity of the tariff-consumption ratio.

In terms of utilities, the average monthly profit estimated for EPSAS is in average 4.3 M Bs/month (about 553,000 Euro), which tends to decrease as a result of the implementation of the new category, i.e., the solidary tariff) (figure 4). Profits for EPSA decreased in average to 4.2 million Bs/month (about 540,000 Euro) for the 2007-2010 period (the period after the implementation of the new tariff).

**Figure 2: Monthly drinking water consumption in the period 2005-2010. The segmented line shows the time at which the solidary tariff was implemented**

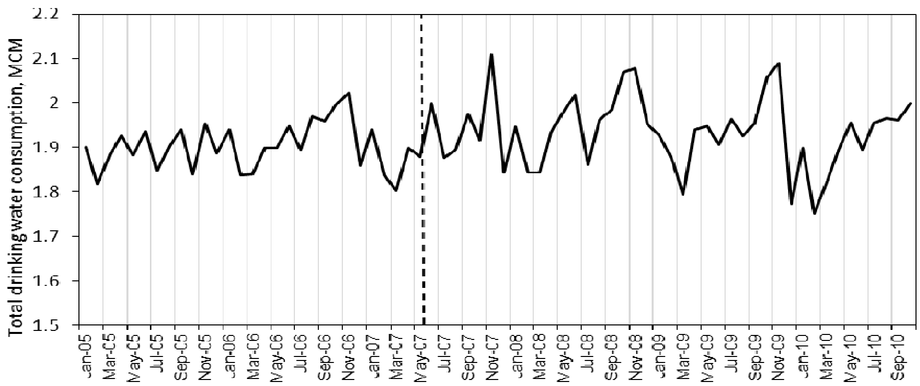



**Figure 3: Consumption per connection in La Paz**

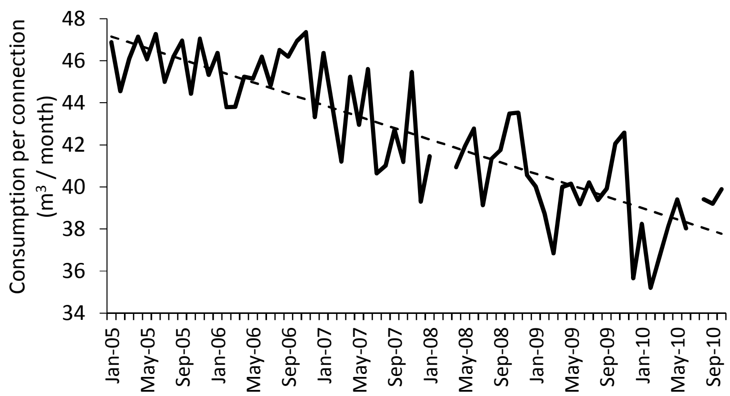
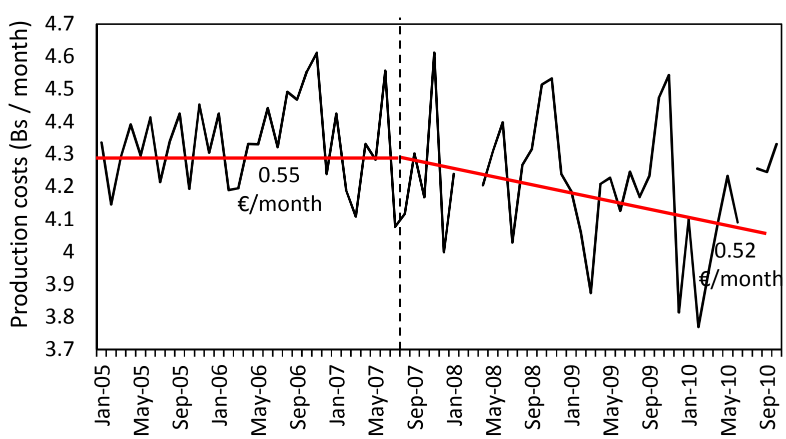



**Figure 4: Estimated income for the drinking water administration company in La Paz**



## 2.3 Price elasticity of water demand

In order to understand the variability of water demand using economic parameters, the method addressed is the price elasticity of water demand. The calculation begins with a regression analysis aimed at understanding relationships among the exogenous variables along the study period (Colmenárez & Salazar, 2016). A multiple correlation matrix is constructed after that, as a mean to express the different levels of association between the dependent and the independent variables. A multiple regression analysis controls many other factors which simultaneously affect the dependent variable; the latter is important for testing economic theories or evaluating policies when using non-experimental data (Colmenárez & Salazar, 2016).

In the economic literature there is no evidence which fully justifies which is the most appropriate functional form for the water demand in the residential sector. For the study case, it is proposed an econometric model based on the production function of Cobb-Douglas, as follows:

$$Q_{tot} = A + \beta_1 \, Conex_{tot} + \beta_1 \, Cons_{tot} + \beta_3 \, Pre_p + \beta_4 \, Cons_{PC} + \mu \quad (1)$$

$Q_{tot}$ = Total water consumption of the residential sector ($m^3$)
$\beta_{1, 2, 3, 4}$ = Elasticities of the variables
$Conex_{tot}$ = Total number of connections in the residential sector in La Paz
$Cons_{tot}$ = Total consumption of the residential sector in La Paz (Bs)
$Pre_p$ = Average cost per cubic meter ($Bs/m^3$)
$Cons_{PC}$ = Per capita consumption; average cost per connection (Bs/connection)
$\mu$= error term

To construct the model, a regression analysis is carried out in order to obtain the values of parameters which accompany the independent variables of the model, in the period 2005-2010. Prior to the analysis, the variables were transformed to logarithmic values, in order to configure the logarithmic base variable matrix. The use of the logarithmic scale buffers the differences between the dimensions of the different variables (Colmenárez & Salazar, 2016).

With the results of the regression analysis, Pearson's partial correlation matrix is established. For the partial correlation study, are considered those values which have more influence on the remaining study variables. The criterion to decide which variables are relevant is obtained through the correlation matrix, by selecting values which are greater than ± 0.50. Positive values would suggest a direct relationship between variables and negative values would suggest an inverse relationship between variables. After the correlation between the independent variables is determined, ordinary least squares are applied to estimate elasticity values.

## 2.4 Future scenarios

In order to add elements to support the analysis, future projections were estimated based on the period of available data, assuming two scenarios. In Scenario 1, all variables are kept invariable but the total number of connections are assumed to increase (Conex tot); it would be unlikely to assume a decreasing trend without the effect of an external factor, not considered in the current model. In Scenario 2 are varied: Average cost per cubic meter ($Pre_p$) and the Total number of connections in the residential sector in La Paz ($Conex_{tot}$).

## 3. Results

### 3.1 Correlation matrix

Considering $Q_{tot}$ as the dependent variable, the variables which reflect the highest correlation are presented in Table 1:

- $Pre_p$ : it shows the highest level of significance versus per capita consumption ($Cons_{PC}$). It explains in 98.18% the price growth by the increase of consumption by connection.
- $Cons_{PC}$ versus $Cons_{tot}$: Pearson coefficient of 0.97. It demonstrates a growth in total consumption, as a consequence of the increase in per capita consumption.
- $Cons_{tot}$ versus $Pre_p$ : Pearson coefficient of 0.96. It demonstrates an increase in the total consumption, as a consequence of the increase in the cost per cubic meter.
- $Conex_{tot}$ versus $Cons_{tot}$ : Pearson coefficient of 0.93. It can be interpreted as an increase in the total consumption, as consequence of an increase in the number of connections.
- $Cons_{PC}$ versus $Conex_{tot}$ : Pearson coefficient of 0.84. It expresses an increase in per capita consumption, as a consequence of the increase in the number of connections.

**Table 1. Correlation matrix, for the identification of factors to be included in the econometric model, where precipitation is *pp* and temperature is *Temp***

| | $Q_{tot}$ | $Conex_{tot}$ | $Cons_{tot}$ | $Pre_p$ | $Cons_{PC}$ | *pp* | *Temp* |
|---|---|---|---|---|---|---|---|
| $Q_{tot}$ | 1 | | | | | | |
| $Conex_{tot}$ | 0.9639 | 1 | | | | | |
| $Cons_{tot}$ | 0.9930 | 0.9349 | 1 | | | | |
| $Pre_p$ | 0.9232 | 0.8556 | 0.9569 | 1 | | | |
| $Cons_{PC}$ | 0.9421 | 0.8417 | 0.9737 | 0.9818 | 1 | | |
| *pp* | -0.0567 | -0.0018 | -0.0566 | -0.0020 | -0.0542 | 1 | |
| *Temp* | 0.0057 | 0.0335 | 0.0058 | 0.0196 | 0.0076 | 0.7007 | 1 |

### 2.4 Elasticity estimation

The results are interpreted considering that the coefficient of determination $R^2$ express the total variance of the variable explained by the regression, with a 95% goodness of fitness. Thus, an $R^2$ adjusted of 0.93, suggests that the model explains about 93% of the total consumption behavior of residential users in La Paz (Table 2).

**Table 2. Regression statistics**

| | |
|---|---|
| Multiple correlation coefficient | 0.99 |

| | |
|---|---|
| Determination coefficient $R^2$ | 0.95 |
| $R^2$ adjusted | 0.93 |
| Typical error | 0.0004 |
| Sample size | 70 |

Tables 3 and 4 show the coefficients of the variables obtained from the regression analysis, representing the elasticities of the econometric model. The proposed model to estimate the domestic water consumption of the city of La Paz in the period 2005-2010 is expressed as follows:

$$Log\ Q_{tot} = -0.24 + 0.039\ Conex_{tot} + 0.970\ Cons_{tot} - 0.330\ Pre_{p} + 0.0023\ Cons_{PC} + \mu \qquad (2)$$

The interpretation of equation 2 is as follows: For each unitary increase in the $Pre_p$, $Q_{tot}$ will decrease 0.330 units (*i.e.,* the price elasticity of demand is -0.330). Such would also be interpreted as follows: a 10% increase in the tariff implies a 3.3% drop in total water consumption in the city of La Paz. The negative coefficient agrees with the economic theory, which suggests an expected indirect relationship between consumption and tariff.

For other variables, the interpretation is similar and would be described as follows: For each unit that increases the number of total connections ($Conex_{tot}$), the total consumption ($Q_{tot}$) in cubic meters, will increase 0.039 units; for each unitary increase in total consumption in Bs ($Cons_{tot}$), the total consumption ($Q_{tot}$) in cubic meters, will increase 0.970 units; for each unitary increase in the consumption per capita ($Cons_{PC}$), the total consumption ($Q_{tot}$) in cubic meters, will increase 0.0023 units.

**Tabla 3. Results of the ordinal least square regression analysis**

| | Coefficients | Typical error | t statistics | Probability | Bounds | |
|---|---|---|---|---|---|---|
| | | | | | Lower 95% | Upper 95% |
| *Intercept* | *-0.245* | *0.0337* | *-7.275* | *5.65E-10* | *-0.312* | *-0.178* |
| *Log* $Conex_{tot}$ | *0.039* | *0.0068* | *5.734* | *2.76E-07* | *0.026* | *0.053* |
| *Log* $Cons_{tot}$ | *0.971* | *0.0037* | *259.380* | *9.8E-100* | *0.960* | *0.978* |
| *Log* $Pre_{p}$ | *-0.336* | *0.0041* | *-81.940* | *2.5E-67* | *-0.340* | *-0.328* |
| *Log* $Cons_{PC}$ | *0.0023* | *0.0037* | *0.634* | *0.528* | *-0.005* | *0.010* |

**Tabla 4. Elasticity values in the econometric model**

| *Variables* | *Elasticity* |
|---|---|
| *Constant* | *-0.2450* |
| *Log Conex $_{tot}$* | *0.0393* |
| *Log Cons $_{tot}$* | *0.9710* |
| *Log Pre $_{p}$* | *-0.3359* |
| *Log Cons $_{PC}$* | *0.0024* |

### 3.3 Future state scenarios

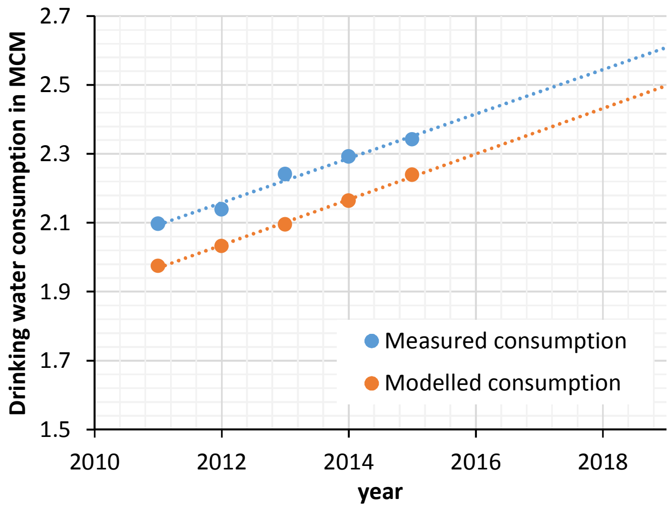
### Scenario 1

The variable with the highest incidence on the levels of total drinking water consumption in the household sector is *Conex $_{tot}$*. EPSAS predicts an increase of 5% in the number of connections, in reference to historical data. Once *Conex $_{tot}$* is projected in the period 2011-2015, the model to project changes in *Conex $_{tot}$* results in the values shown in Table 5, denoting an increase in the total consumption with respect to the econometric model initially proposed. Graphically, the difference between modelled and measured (estimated) consumption, it is also evident (Figure 5).

**Tabla 5. Projected values according to the proposed model**

| Year | Log *Conex $_{tot}$* | Log *Cons $_{tot}$* | Modelled consumption | Measured consumption |
|---|---|---|---|---|
| 2011 | 5.334 | 6.296 | 1,975,195 | 2,097,203 |
| 2012 | 5.654 | 6.308 | 2,032,783 | 2,139,147 |
| 2013 | 5.993 | 6.321 | 2,095,660 | 2,241,531 |
| 2014 | 6.353 | 6.335 | 2,164,435 | 2,292,669 |
| 2015 | 6.734 | 6.350 | 2,239,802 | 2,342,841 |

**Figure 5: Consumption projection for the period 2010-2018**



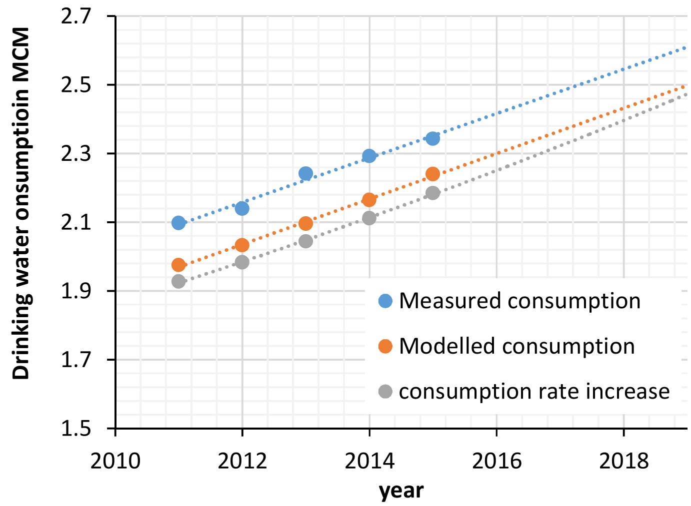

### Scenario 2

Modelled values are obtained with a 5% increase in the number of connections per year and a 10% increase in the cost; cost per cubic meter (*Pre* $_p$) and total number of connections (*Conex* $_{tot}$) are converted to their logarithmic base in order to be considered in the econometric model proposed. When considering an increase in the number of connections compared to an increase in consumer prices per cubic meter, it is predicted a reduction of 2.44% in the total consumption of drinking water, with respect to the projections without the increase of the previous scenario (see Figure 6). Thus, the increase in the cost of water has inverse effects on household water consumption (Table 6).

**Tabla 6. Projected values with the model**

| | | | No increase | | With an increment of 10% | | |
|---|---|---|---|---|---|---|---|
| Year | Log *Conex* $_{tot}$ | Log *Pre* $_p$ | Log *Cons* $_{tot}$ | Consumption | Log *Cons* $_{tot}$ | Consumption | Reduction% |
| 2011 | 5.3338 | 0.358 | 6.2956 | 1,975,195 | 6.2849 | 1,926,878 | 2.5 |
| 2012 | 5.6538 | 0.358 | 6.3081 | 2,032,783 | 6.2974 | 1,983,057 | 2.5 |
| 2013 | 5.9930 | 0.358 | 6.3213 | 2,095,660 | 6.3106 | 2,044,396 | 2.5 |
| 2014 | 6.3526 | 0.358 | 6.3353 | 2,164,435 | 6.3246 | 2,111,489 | 2.5 |
| 2015 | 6.7338 | 0.358 | 6.3502 | 2,239,802 | 6.3395 | 2,185,012 | 2.5 |

**Figure 6: Consumption behavior with and without an assumed increase**




## 4. Conclusions

The elasticity-price of the drinking water demand of the residential sector in La Paz in the period 2005-2010 is inelastic, as indicated by the -0.33 coefficient according to the proposed econometric model. The analysis for the domestic drinking water demand during the 2005-2010 period, indicates that the amount of total water consumed depends on the average price, consumption per connection, total invoiced consumption and total number of connections. Thus, the pricing policy implemented by the company in charge of the system administration through the study of the solidary tariff in the periods 2005-2010, resulted in a decrease in the per capita consumption or consumption per connection.

An increase in the cost of water for the household sector results in a reduction in the amount consumed. Although the regulation by the application of tariff measures can help to rationalize the use of water by city users, when it is aimed an optimal strategy towards optimizing drinking water consumption (an optimal model), strategies should be accompanied by educational and informative campaigns aimed at raising awareness among the population about the actual value of the resource; would also be beneficial the application of incentive programs for the use of water saving technologies or measures aimed at improving the efficiency of the distribution system, avoiding among others, water losses in the system.

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**Comunicación alineada con los Objetivos de Desarrollo Sostenible**